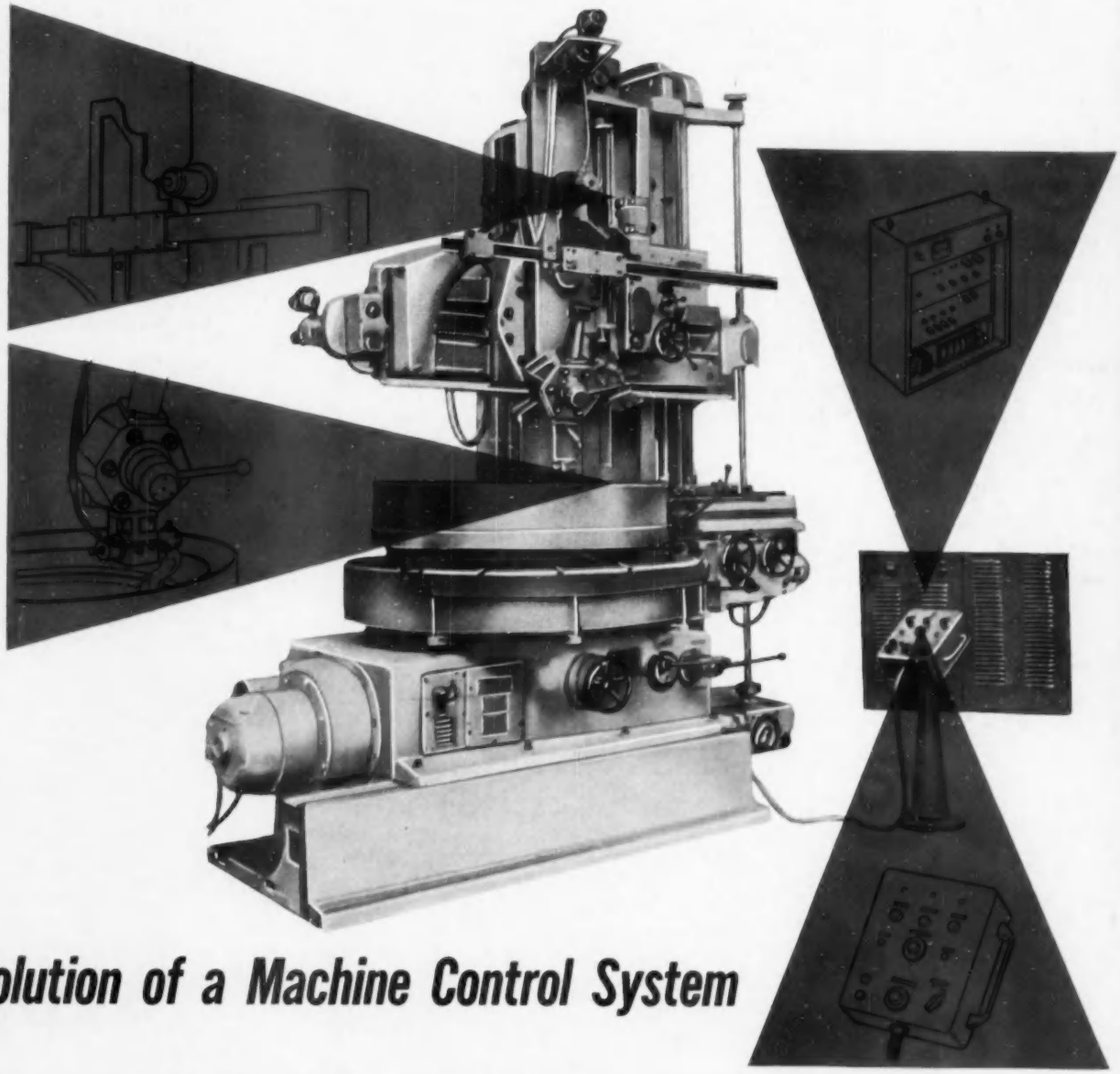
Control ENGINEERING

INSTRUMENTATION AND AUTOMATIC CONTROL SYSTEMS

A McGRAW-HILL PUBLICATION

PRICE 50 CENTS

APRIL 1956



Evolution of a Machine Control System

ALSO IN THIS ISSUE

Pneumatic vs. Hydraulic Actuation

Nonlinearities in System Design

How Computers Handle Arithmetic

the new approach to large scale computations in automatic systems design!

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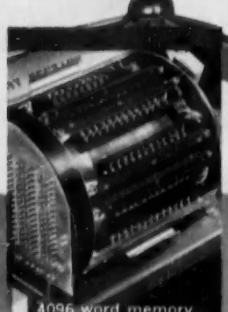

4096 word memory

SPECIFICATIONS

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30 bits, and sign
Mode of Operation:
Serial, one address
Program Storage:
Internal
Access time:
8.5 ms av. 2 ms min.
Transfer time:
1 ms min, 17 ms max.
+ time: .26 ms
÷ × time: 17 ms
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One word defines the "new approach" of the LGP-30...SIMPLICITY. *Operating Simplicity*...for the average engineer...made possible by the elimination of non-essential commands. Programming techniques are easily mastered. *Design simplicity*...that results in complete mobility. The LGP-30 may be operated from any 115 Volt AC outlet. *Service simplicity*...because fewer components, conservatively operated, mean less "time-out" for maintenance. And, too, the LGP-30 costs considerably less than any other general purpose computer—to buy and operate.

Write for brochure describing applications, operation and detailed specifications.

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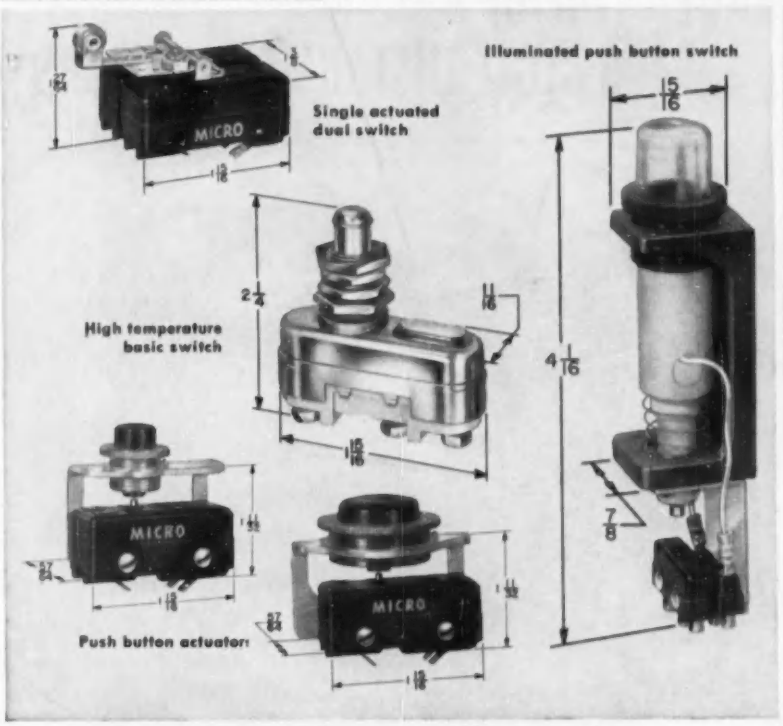
MICRO precision switches

...THEIR USE IS A PRINCIPLE OF GOOD DESIGN



A continuous flow of Precision Switch developments anticipates designers' needs

Function of MICRO SWITCH Engineering, both at the factory and in the field, is to supply the precision switch which most exactly meets the design requirement.

Shown here are just a few recent MICRO SWITCH developments that designers have found useful in a wide variety of applications. Write to any branch office or to Freeport, Illinois for more detailed information.

The Single Actuated Dual Switch consists of two basic switching units operated by a roller lever actuator. The operating point of one of the basic switches is field adjustable so either simultaneous actuation or a definite sequence of operations is possible.

The Illuminated Push Button Switch is a low force, high pre-travel switch with an indicating light as an integral part of the push button. The high pre-travel permits movement of the button before the contacts snap over. This switch is designed for use in electronic, aircraft, mobile, marine, railway and other low voltage a-c or d-c applications.

The High Temperature Basic Switch is a precision snap-action switch which will operate satisfactorily in a temperature range of from −50° to plus 1000° F. It is useful in such industrial applications as found in distilleries, foundries, vulcanizing plants and other industries which require high temperature components.

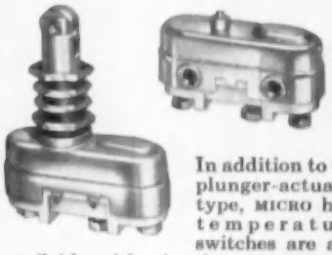
Push Button Actuators are of a new series available to designers of electrical computers and other types of commercial and industrial devices which require reliable panel-mounted, manually-operated switches. They are available with ½" or 1" buttons and combine attractive appearance and extremely long life with an exceptionally good actuation "feel".

Manufacture of precision switches is not a side line with MICRO SWITCH. It is our entire *business*. That is why industrial designers come to us more and more each year with switch problems of amazingly diverse types. MICRO SWITCH branches are conveniently located to serve you.

Illuminated Push Button Switches allow mounting on one inch centers

MICRO SWITCH Illuminated Push Button Switches are outstanding for ease of operation, high pre-travel, compact design (which permits mounting on one inch centers), smooth appearance and easy-to-see pilot light. Switches are provided with sockets for a single contact miniature bayonet lamp. Removable translucent push buttons are available in clear, red, or frosted white.

High Temperature Switch comes in three actuator types



In addition to the plunger-actuator type, MICRO high temperature switches are also available with pin plunger actuators for use where space is limited and small operating motion is available. Roller plunger actuators are provided for applications where cam or slide action is required.

How Push Button Actuators are mounted to a panel

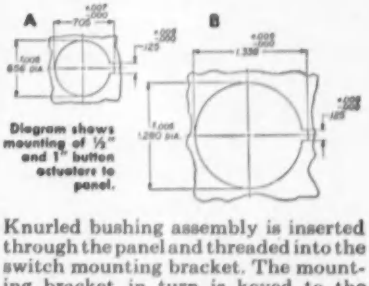


Diagram shows mounting of ½" and 1" button actuators to panel.

Knurled bushing assembly is inserted through the panel and threaded into the switch mounting bracket. The mounting bracket in turn is keyed to the panel, using Mounting details A or B.

MICRO SWITCH Engineering Service is available to help you select the exact switch to meet your design problem. Call the MICRO SWITCH branch nearest you.

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Control ENGINEERING

APRIL 1956

INSTRUMENTATION AND AUTOMATIC CONTROL SYSTEMS

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SHOPTALK

THE FRENCH HAVE A WORD FOR IT

Our cover design and lead article on page 65 describe the systematic evolution of a very neat Gallic machine control system. One of our people overseas got wind of this work and asked Monsieur Jeudon to write it up for CtE. In the ensuing months, while guiding this article into print, we became aware of two things: 1) the extreme competence and cooperativeness of the French control engineers who did the job, and 2) the inherent capacity of technical French to be transformed lucidly into English. Incidentally, at the close of the correspondence, we asked the author how we should pay him the "small honorarium" for his article. He replied that a three-year subscription to CtE would be adequate. Perhaps "small honorarium" is different in French, for we had to explain that the subscription only uses up $30 of the $200 we would like to send him. We should have been more "franc" about it to begin with.

PERAMBULATING PULSES

Industry's Pulse this month (page 55) makes two departures: from its usual coverage of control commerce, and from the U.S. scene. For this one we asked engineer Mel Fusfeld to send us his comments on European control while he's on a half-year journey about the continent. A recent letter indicates that Mel is right in there—but that he usually has to answer as many questions as he asks. "As a matter of fact," he notes, "I have even been invited to deliver a lecture series at the University of Delft. And, after lunching with the president of the Bell Telephone Co. of Belgium, I am supposed to address the Royal Belgian Technological Society." Mel finds process plants in the Low countries "right at the top" technically—despite an apologetic attitude "probably due to too much American ballyhoo". Other "Perambulating Pulses" will explore this point.

A CHALLENGE TO DESIGNERS

During the recent unveiling of the *Datamatic*-1000 (page 28) we were handed a slim envelope containing one "Woo"—a diminutive magnetic core developed by Dr. Way Dong Woo, Datamatic staff engineer. Back in the office we added the "Woo" to our bulging drawer of free samples—and then took inventory. Among objects on hand: a nylon-insulated thermocouple; two transistors embedded in lucite; a thermal overload relay; four Tinkertoy modules; a midget 12-contact printed circuit connector; an optical coated disc; a dime-sized 2K silicon rectifier; and one small 0-15-lb bellows. A staff meeting was called for ideas on how to use this material. One possible project: a system that starts the wall fan when an editor overheats.

MEMO

FROM: The custom engineering staff at NJE

TO: Designers of computers, telemetering equipment, TV transmitters, etc.

SUBJECT: **Why SEMI-Regulated Power Supplies?**

We receive over twenty-five requests each week for custom power supply quotations. Most of these requests are obviously built around vacuum-tube or mag-amp regulated power supplies.

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.....over thirty percent of these applications do not require regulated supplies. We usually recommend our ELG type, which is simpler, cheaper, and much more stable. Typical life expectancy is in excess of 50,000 hours without maintenance. No heat. No mag-amps. No saturable reactor. No "trick tubes". No tubes at all in fact.

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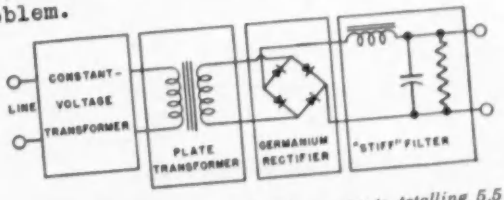
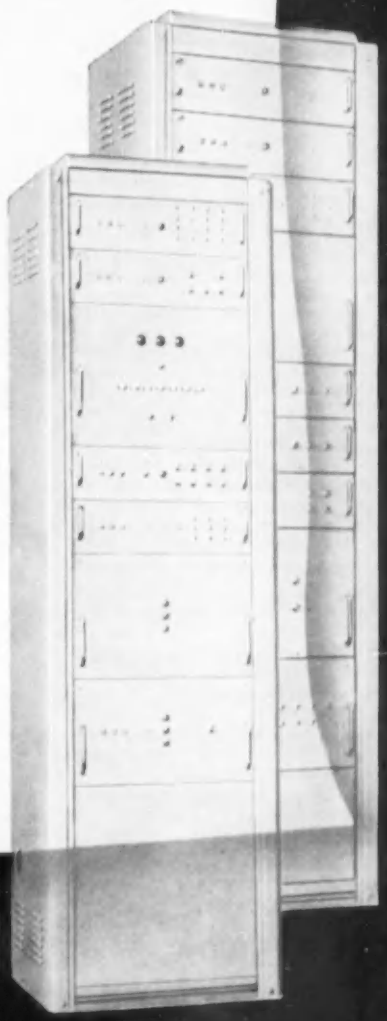


A good example: *Thirteen outputs totalling 5.5 KW of well-regulated, well-filtered, transient-free DC power for a computer. Priced about $8,000. (Would have been about $15,000 with regulators.) Occupies two cabinet racks. (Would have been 5 racks with regulators.)*



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See electronics Buyers' Guide Pp. 113-120

NJE

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Type C. Two relays on the same frame; mounts in same space as the "A" type. It is particularly effective where small space is a factor.

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FEEDBACK

THE PROBLEM FORUM . . .

. . . usually presents a measurement or control problem submitted by a reader or found by the editors while on tour. To date many readers have furnished scholarly solutions — which we have recognized with modest cash awards and by publishing these solutions for the edification of all our readers. Future contributors of problems and solutions can expect the same tribute.

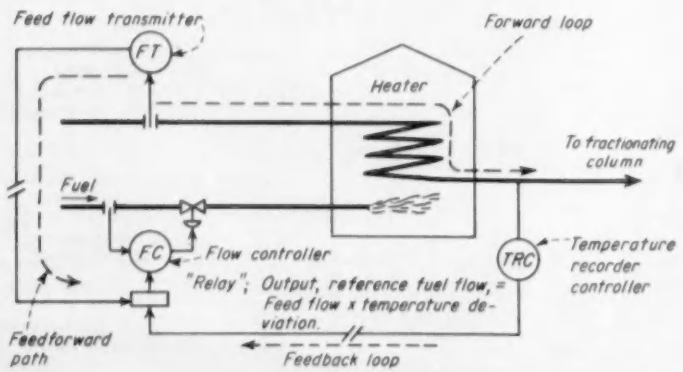
This month our problem deals more with semantics than pedantics: it offers the challenge of a word, and solicits your reaction to it.

April Fooler

"Feedback", "feedback loop", "forward loop" are all words and phrases that originated with the engineers and scientists who developed means of analyzing and designing electronic feedback amplifiers. As the principles of designing feedback systems spread into mechanical, aeronautical, and chemical engineering, a great deal of electronic terminology was carried over. It served well, but the control engineer found it necessary to develop words to cover new situations. Such a word is "feedforward". An example of its use is diagrammed below.

"Relay" maintains constant ratio of fuel flow to feed flow as long as temperature deviation from reference temperature is zero. Feed flow signal "feeds forward" to fuel flow controller, delayed only by the transfer lags of the flow transmitter, the transmission line and the receiver in the "relay". If then, the temperature response to fuel flow change is not matched to the temperature response to feed flow change, the system makes an incorrect change in temperature. Therefore, the dynamics of the "feedforward" path must be matched to the forward loop dynamics.

If you find the word "feedforward" makes sense, send us other examples of its usefulness. If, on the other hand, you think that it is nonsense, let us know. We'll summarize your comments and pass on the whole file to the American Standards Association committee on the terminology of automatic control.



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That continual problem, terminology . . .

To the Editor—

Would you find it correct to use the word "automize" instead of "automatically controlled" in combinations such as . . .
"automized equipment of units" . . .
"automized circuits of steam and liquids" . . .?

L. Wachtel
(Consultant in heat exchange)
Glen Ridge, N. J.

We can't wax very enthusiastic about Mr. Wachtel's proposal to use "automized". An ironic typographical error could result in "atomized equipment". If an engineer means automatic equipment or automatic circuits, why doesn't he say so? What can he gain, besides confusion, by generating trick words and phrases? Ed.

Reader bats 500 . . .

To the Editor—

I, (along with many other readers, I am sure), have detected two errors in the article "How Stabilization Improves Closed-Loop Operation" by Davidson and Nashman in the December issue. Since this article may be widely used by those only slightly familiar with servo theory, I feel that they should be pointed out to your readers.

On page 70 under Laplace Transformation, the transform for a step input $f(t) = 1$ is given as $F(s) = s$, which is very much in error. The correct transform should be $F(s) = 1/s$ for a step input.

Davidson's answer:

The first comment is valid, and the mistake is of course due to a typographical error. This discrepancy in the Laplace transform of a unit step has been pointed out by other readers.

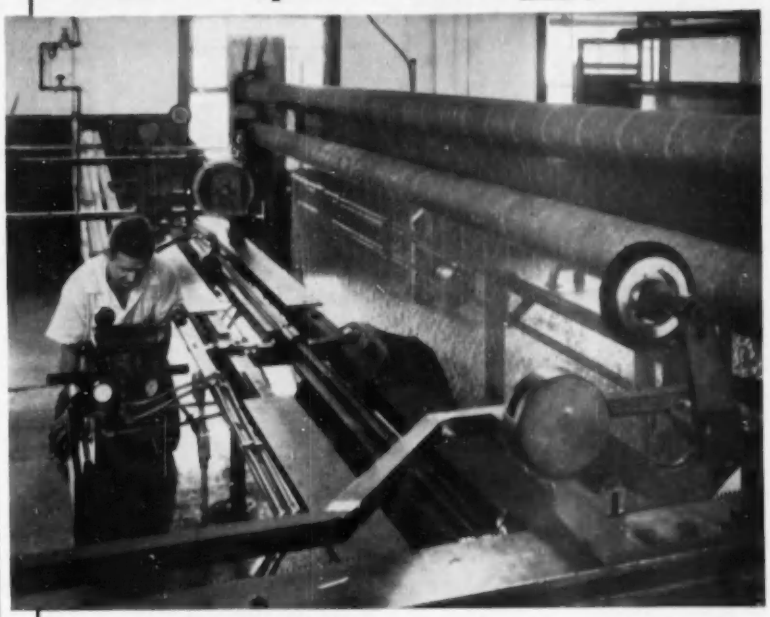
On page 71, under Frequency Response, the fourth paragraph states the Nyquist criterion in an incorrect manner. The open-loop transfer function plot can enclose the -1 point and still be stable and, in fact, frequently does. If the number of enclosures of the -1 point is equal to the number of poles of the open-loop transfer function, then there are no zeroes in the open-loop function and the system is stable even though the -1 point may be encircled several times.

And Davidson's reply:

The Nyquist criterion as given was stated to apply only to a single-loop system. This is correct as such and in fact the criterion is usually applied in this form. For multi-loop systems, a more general statement would be that

FROM...

Tons of Steel to Ounces of Lace Rolls of Paper or what YOU Make



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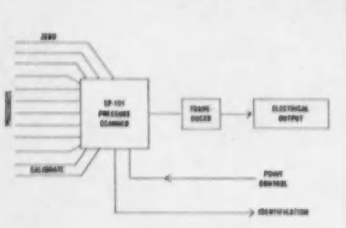
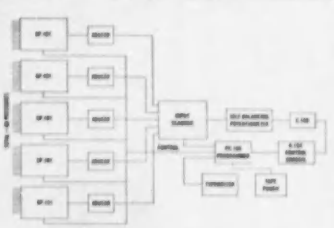


TYPICAL SYSTEM USING ONE TRANSDUCER



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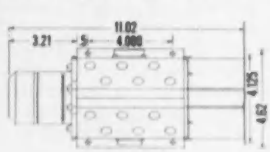

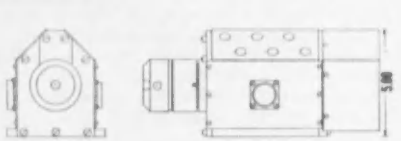

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FEEDBACK

for a stable system the number of enclosures of the −1 point is equal to the number of poles of the open-loop transfer function in the right-hand half plane. In the case of a single loop with physical elements, the open-loop transfer function can have no such poles, and hence the criterion as stated in the article is applicable.

Point . . .

To the Editor—

I realize that Control Engineering attempts to discuss technical topics on a more practical and less theoretical level than do the "Transactions" or "Proceedings" of the various engineering societies. In this attempt, it has been succeeding admirably. As an engineer, I can take my mathematical rigor or leave it alone (preferably the latter), but I think definitions should attempt a degree of precision. I refer to Mr. Stout's article on nonlinearity in the February 1956 issue, which at one point defines a linear system in terms of one of its properties—the principle of superposition. I will accept superposition as a test of linearity but not a definition of it[1]. The definition of a linear differential equation in the same article also suffers from a lack of precision. It can be simply stated as follows: A differential equation of any order is linear when it is of the first degree in the dependent variable and its derivatives[2]. By Mr. Stout's definition, an equation with a term $\left(\frac{dx}{dt}\right)^2$ is linear where such is obviously not the case.

I also wish to take issue with Mr. Coales (same issue) in some of his statements. He says, "Most known comparators or detectors behave according to a square law relationship. . . ." Some do, but please qualify that "most". How about synchros, resolvers, potentiometers, and resistive adders, among comparators; and thermocouples, D'Arsonval movements, Bourdon gages, and proportional ion chambers, among the detectors?

1. Gardner & Barnes: "Transients in Linear Systems", p. 5
2. Kells: "Elementary Differential Equations", p. 49

Milton J. Lowenstein
New York, N. Y.

. . . and counterpoint

Zadeh ("A General Theory of Linear Signal Transmission Systems", *Jour. Frank. Inst.*, April 1952) says a system

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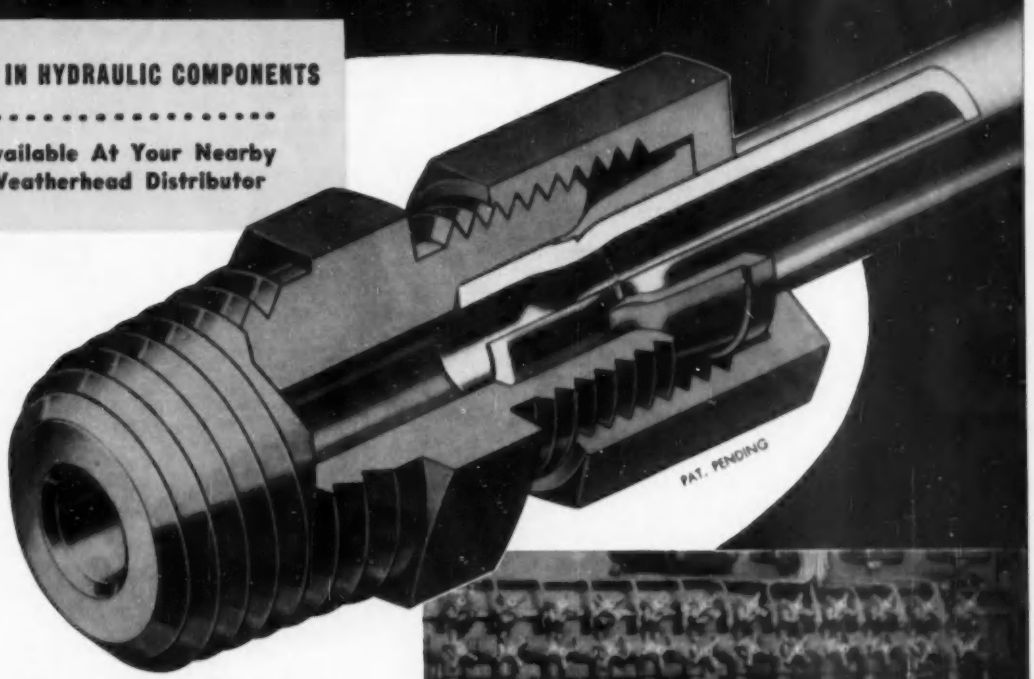

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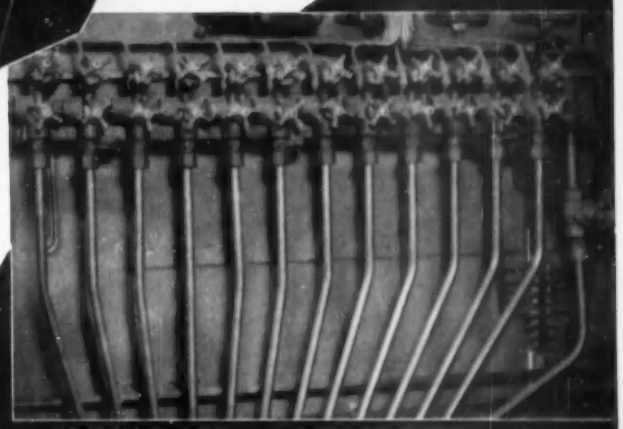

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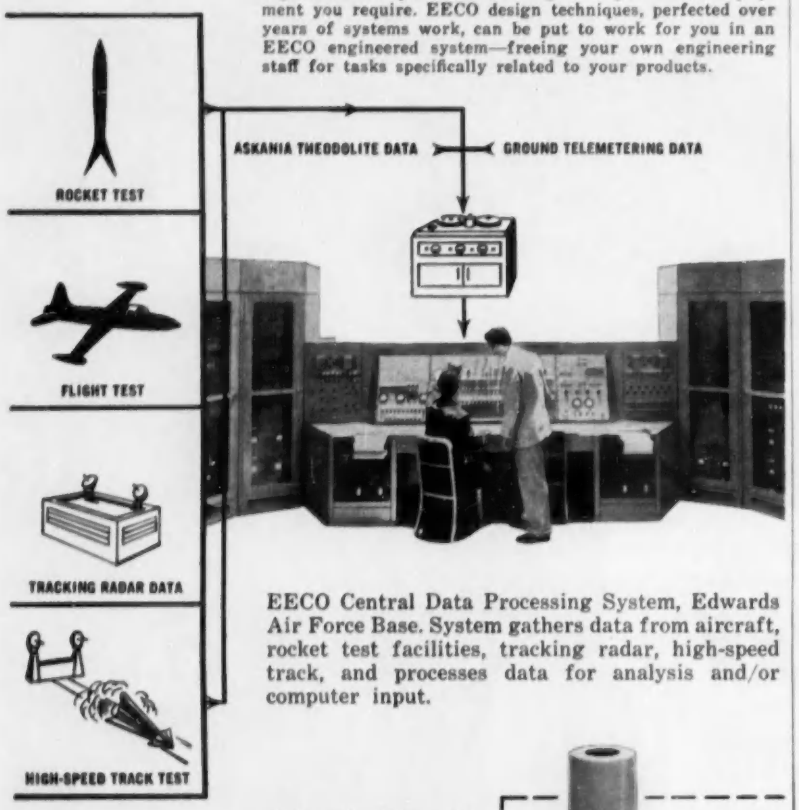

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FEEDBACK

is linear if it has the additive property (i.e., obeys the superposition principle). The Radiation Lab volume on servomechanisms (Vol. 25) says about the same thing on pages 28-29. I don't think Mr. Lowenstein's argument on this point is justified, the manner of definition being a matter of choice rather than rigor.

He may be technically correct that the definition of a nonlinear differential equation is incomplete. However, his $(dx/dt)^2$ can be interpreted as

$$\left(\frac{dx}{dt}\right)\frac{dx}{dt}$$

i.e., a derivative term with a coefficient that is proportional to the derivative of the dependent variable, a situation included in the statement. Similarly, a term in sin x could be written

$$\sin x = x - \frac{x^3}{3!} + \frac{x^5}{5!} - \frac{x^7}{7!} + \cdots$$

$$= x\left[1 - \frac{x^2}{3!} + \frac{x^4}{5!} - \frac{x^6}{7!} + \cdots\right]$$

$$= x\,f(x)$$

to fit the statement in the article. If there is an omission, the most important oversight concerns the possibility of coupling terms like x y or y dx/dt in sets of simultaneous equations.

The lack of precision in the definition, if any, resulted from a desire to show the difference between equations with time-dependent coefficients (linear) and amplitude-dependent coefficients (nonlinear). This difference is not always appreciated, and I wanted to emphasize it. The example of the nonlinear equation was chosen with this point in mind and does not illustrate all the possibilities explicitly, although it can be interpreted to cover most of them.

T. M. Stout
Schlumberger Instrument Co., Ridgefield, Conn.

Process control engineer praises and prods . . .

To the Editor—

May I offer a suggestion for the improvement of your excellent magazine?

Many of us old (ChE '32) process engineers have drifted into the field without formal control education. We have nothing but "hunches" to offer the process design engineer as to the controllability of a process, yet we write the specs and direct the procurement of the majority of plant process control equipment. We need

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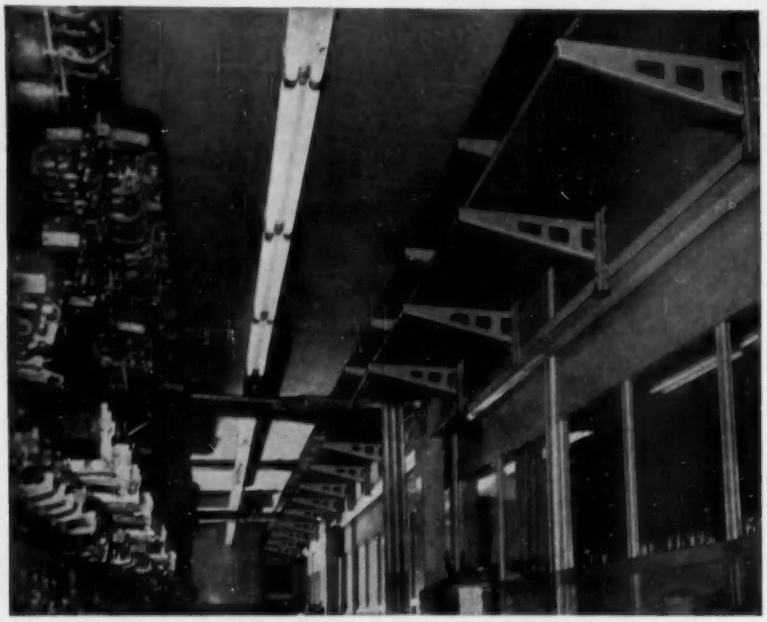

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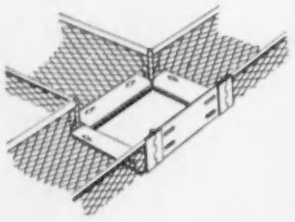

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FEEDBACK

more lucid articles on the same educational level as that by Mr. Zoss of the Taylor Instrument Companies "How to Reckon Basic Process Dynamics", CONTROL ENGINEERING, Vol. 3, No. 1, January 1956.

Even the article by Mr. Zoss baffles me at one point. The article suddenly switches from a logically developed transfer function to a plot of frequency response. The inference is that the frequency plot is developed from the transfer function, but the method of development is not shown.

Another suggestion for the improvement of your magazine is that the principles of clear writing may be extended to the writing of mathematical formulas. Enough Greek letters can make gobbledegook of the simplest equation. This is particularly true where a symbol represents an abstract value not easily expressed in a few words. Legends should appear at each equation, or at least on each page symbols are used. Mr. Zoss' article is a shining example of the way these things should be. For instance, in making a heat balance, Mr. Zoss uses the term, $Q_{storage}$. Many writers would use the term, Q_s.

Louis D. Kleiss
Phillips, Texas

The transfer function describes the time behavior of the item studied; the frequency-response equation or plot shows how it acts when the frequency of a sinusoidal disturbance changes. The editors will present, soon, a short article that explains the conversion from transfer function (expressed as a differential equation) to frequency response.

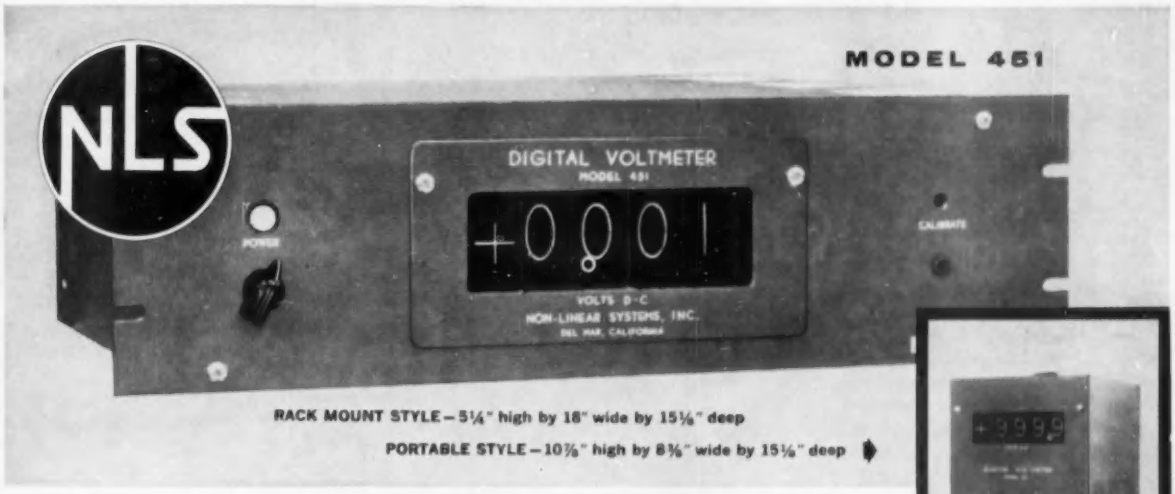
'Nough said about symbols. We heartily agree with Mr. Kleiss' praise of Mr. Zoss' use of symbols in mathematical expressions and will endeavor to follow his example. Ed.

Uncle Sam wants YOU . . .

TO THE EDITOR—

Your magazine is known to reach readers who can fill vacancies that exist here at the Air Force Armament Center, Eglin Air Force Base, Florida. Inasmuch as we are prohibited by regulation from placing paid advertising in order to inform those who would be interested in our opportunities, we hope that your magazine will publish this information so that these men may realize the need for their services.

The Armament Center has recently been given the responsibility for the development of aerial munitions, in-



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cluding guns, bombs, rockets, fuses, guided missile warheads, and related equipment, exclusive of nuclear weapons. Positions in fields covered by this responsibility have now become open, and are currently being filled. Our openings lie mainly for those qualified for Civil Service grades between and including GS-5 and GS-14. The personnel most urgently needed are physicists, mechanical engineers, ballisticians, and especially electronic engineers. Applicants chosen in these grades may expect to receive between $3,670 and $10,320 annually.

Any readers interested in applying for jobs at the Armament Center should submit a Standard Form 57, Application for Federal Employment, available at any first-class post office, to the Civilian Personnel Office, 3201st Air Base Wing, Eglin Air Force Base, Florida. Any information they desire may be obtained by writing to the same address.

Needs for various scientists and engineers in the above and other fields will continue at the Armament Center during the foreseeable future. Therefore, if any reader should doubt his qualifications, he is urged to contact the above office.

Harry R. Beamer
Lt. Colonel, USAF,
DCS/Personnel

The ultimate customer of this magazine is a group of readers who can do critically important work across industry. As it is our job to fully acquaint our readers with professional opportunities as well as the techniques and equipment used in their work, we publish this letter as a service to them. Ed.

Looking for a needle . . .

To the Editor—

On page 20 of the January 1956 issue of Control Engineering you have a new item datelined New York, Oct. 20-21 concerning The Institute of Management Sciences.

Can you tell me the official address of this organization or how I might contact them to obtain copies of the proceedings of their meetings?

Thank you for your cooperation.

Raymond C. Dietz
Richmond Hill, N. Y.

Write for further information to Mr. Alex Orden, Secretary-Treasurer of The Institute of Management Sciences. His address: Research Center, Burroughs Corp., Paolia, Pa. Ed.

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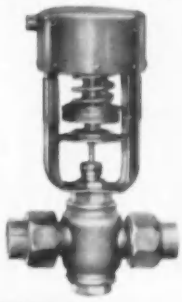

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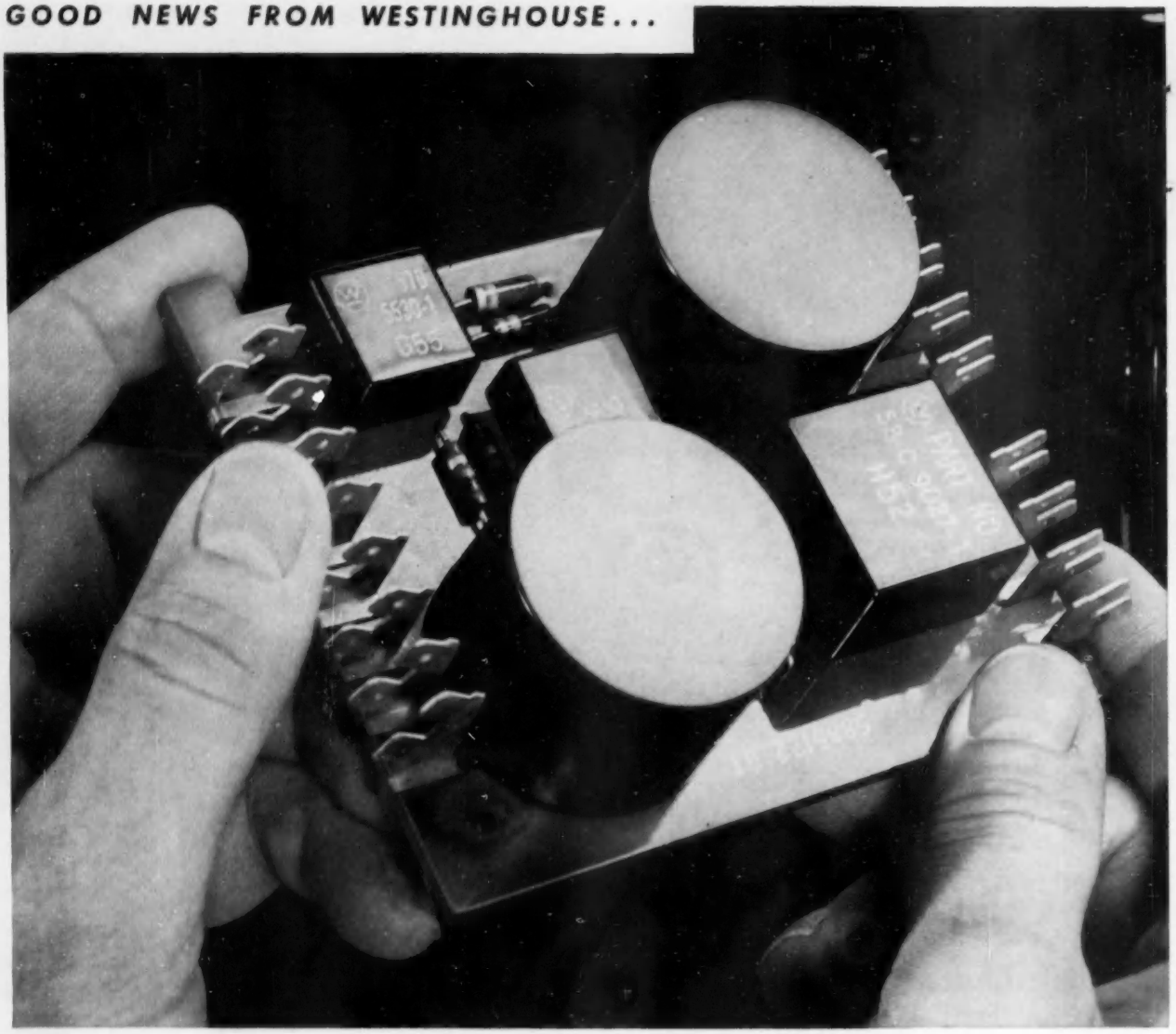

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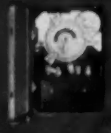

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How did engineer-scientist-philosopher Herbert W. Ziebolz get that way? It started when the young graduate (Masters in ME cum laude, Breslau Technical Institute, '26), already reading and thinking beyond the parochial boundaries of straight engineering, made this discovery: *technology grows at an exponential rate—hence it is possible to extrapolate the present into the future.* This became his guide. Henry Ford's biography—fraught with the future—inspired him to visit the United States as a postgraduate industrial exchange student. After two years of studying mass production methods in auto plants he was convinced that the future—his future—lay in the U.S. Back in Germany, while waiting for his visa, he went to work as assistant to the chief engineer of Askaniawerke's Industrial Control Div. in Berlin.

Finally, in 1931, Bert Ziebolz returned to this country to manage the production, service, and design of hydraulic controls for American Askania Co. in Chicago. In '36 the company joined the H. A. Brassert Co. under the name of Askania Regulator Co. and Bert became its V-P of engineering—a position he still retains, although Askania now is an affiliate of General Precision Equipment Corp.

A patent catalyst

As the years passed, the prolific Mr. Ziebolz found himself spending more and more time in Washington to substantiate his patent claims. Bert considered the future and took a bold step: he developed a new approach to the design of computer and control elements that revealed analogous ways to accomplish the same function electrically, pneumatically, hydraulically, and mechanically. Publication of this approach allowed other patentees of similar devices to use the phrase "well known to those skilled in the art" without fear of challenge by patent examiners, thus minimizing litigation and speeding up patent processing in Bert's field. And though immediate benefit went to others, the move provided Ziebolz, who now has 71 patents to his credit, with extra time for his creative work.

With Ziebolz, theorizing extends beyond the blackboard.

During World War II Bert was placed in charge of development and design of submarine training devices for the U. S. and British navies. He soon branched out into design of special submarine controls and formed the special devices section of Askania. For this work he was cited by the Chief of the Bureau of Ships and in 1954 the Instruments and Regulators Div. of ASME honored him.

Still ranging far afield

Ziebolz, usually accompanied by his wife, Hilda, travels extensively over the world on business and vacation. The impressions he gets—from people, books, and situations—"build up my enthusiasm for the creative job of engineering. They allow me to relate experiences elsewhere to the prediction of trends and recurring cycles in cultural, scientific, and technological development." His predictions, however, sometimes involve unusual subjects. Many years back he foresaw rabid interests in African sculpture, unadorned furniture, and flatwall church design. They all came to pass.

Now only 53, Bert keeps assaying the future and making his own long-range plans. One project will be to rewrite a certain book—originally in Hungarian, now in German—into English. This book has profoundly influenced Bert and he believes it will create great interest in America. We'd like to publish that book . . . for Bert Ziebolz is usually right.

Facing an eminent audience, Director A. V. Astin holds forth on new ways to measure Mass and Force—a scholarly but lively orientation just before the . . .

National Bureau of Standards Parades Its Skills in Measurement

WASHINGTON, D. C., Jan. 23—Scientists and engineers are supposed to be notoriously poor showmen, but this theory went into a cocked hat at the National Bureau of Standards' annual Open House this week.

Things started off quietly enough. When the hundreds of industrial, scientific, and government leaders who were invited sat down amidst giant testing machines in the three-story Engineering Mechanics Lab, scholarly Dr. A. V. Astin started to dissertate on Bureau plans to redetermine g, the pull of gravity. But then things started to pop. Down plunked a steel ball from a shelf high above the audience, to reenact—and improve upon—Galileo's gambit with a cannon ball atop the Tower of Pisa. Next, with closed-loop TV and massive offstage machines, the good doctor showed how to play with mighty large forces: a 1-million-lb dynamometer was calibrated on a 10-million-lb testing machine (the world's most powerful); a stoutly welded ship's plate was deformed under a mere 2.3-million-lb pressure; a mammoth magnet aligned spinning hydrogen nuclei in a small vial of water.

Bounced completely off the edge of their seats by these doings, the guests were next herded into groups and whirled through the Bureau's laboratories where 15 skillfully organized ten-minute demonstrations revealed these brilliant samples of the fundamental and advance-guard work going on at the remarkable institute:

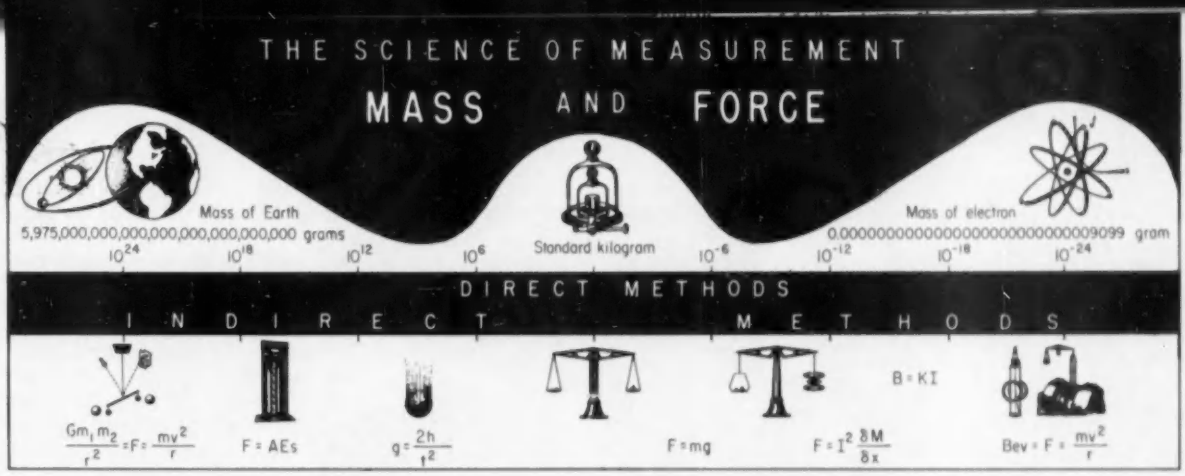
- an analog simulator that computes and scope-displays the geographic pattern of radioactive fallout from a nuclear explosion
- a unique iridium-iridum/rhodium thermocouple able to measure and withstand 3,000 deg F and up.
- the new "forward scatter" technique of radio wave propagation, which vastly extends limits of long-distance communication
- a "physiological monitor" that dynamically records patient heartbeat, blood pressure, and respiration during an operation

Aside from these and several other spectacular items, the tour had many solid points of interest for the visiting control engineer—four of the pertinent labs, for example, are on view on the opposite page. He would have been enlightened by the Bureau's new Radiation Laboratory and the excellent work it is doing to set up secure standards for "hot" materials now being used in over 2,000 industrial and institutional nuclear-type gages. And he would have been fascinated by the painstaking temperature-impurity corelation that the Bureau uses in controlling the purity of titanium.

The Purpose and the People

NBS's parade of skills and accomplishments also offered a revealing glimpse of the importance of this agency to our economic as well as our scientific life. Behind the displays and talks lay its main function: custodianship of our national standards of physical measurement. The Bureau is our ultimate source for standards of accuracy and reliability in instruments, devices, even interchangeable parts. It provides the methods to measure conformation to these standards and offers calibration services to insure their accuracy.

Doing the work at NBS are 2,800 people, 40 per cent of whom are professional scientists and engineers. The mettle of these people is obvious in the brilliant quality of their work, and in the enthusiastic—yes, showmanlike—way they show it to visitors.



HOW THE BUREAU DEALS WITH MASS AND FORCE

All measurements of mass and force in this country are based on the national standard of mass, a platinum-iridium cylinder (center of chart), kept in the custody of the Bureau. Measurements of mass and force extend over a tremendous range—from the mass of the earth (left of chart) to the mass of the electron (right of chart), from the 10-million-lb force exerted by the Bureau's giant materials testing machine (lower left) to the small forces exerted by atomic particles.

In measuring mass and force scientists need to know very accurately the acceleration of gravity, g. This is a measure of the pull of the earth and defines an exact relationship between mass and force. The Bureau plans to redetermine g by the falling body method (left of balance).

The Bureau's current balance (right of conventional balance) is an example of how force measurements and the accurate determination of g enter into absolute determinations of the ampere.

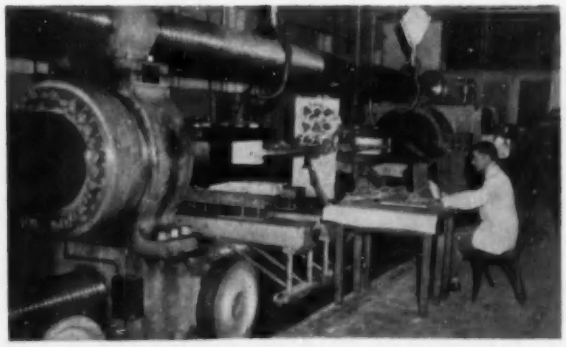
Deflection of an electron beam by an electromagnet (right of current balance) illustrates the principle used in the mass spectrometer to determine the masses of atoms and molecules.

Recently the Bureau used the current balance principle to make very accurate determinations for evaluating the mass of the electron and magnetic moment of the proton (lower right).

SOME OF THE THINGS THEY SAW ON PARADE

DIGITAL COMPUTER—the Bureau's famous SEAC—was paced through a simple problem. SEAC is kept very busy solving a wide range of problems for government agencies.

ANALOG COMPUTER demonstration included graph-solving a sample equation with general-purpose unit (left) and vivid simulation of atomic fallout in special analog (right).



STRAIN GAGES were used to pick up data on the distortion of a welded ship's plate (center) in this 2.3-million-lb horizontal testing machine. Note TV camera on scene.

DISPLACEMENT AND THICKNESS measurements in inaccessible places got the spotlight on this Electronics Div. bench. A way to gage steam turbine clearances was shown.

CONTROL CONCLAVES

San Francisco, Feb. 7-9

Experts who attended this fourth western meeting of the Joint Computer Conference sponsored by AIEE, IRE, and ACM (see January issue, page 22, for a report on the recent Eastern meeting) feel that, as a yearly event, it may be nearing the point of diminishing returns. Our man picked up comments such as these:

- from a process industry scientist—". . . very little at this show that I didn't see last year. Two trends are evident, however: the use of punch cards and tape to tie equipment together, and the ascendancy of digital over analog for representing various phenomena."
- from a control manufacturer-engineer—"The most interesting things in the computer field are kept hush-hush . . . and most talks are more sales-pitch than informative. The most notable aspect of the affair is its being run somewhat like a hiring hall—the upstairs company rooms are interviewing like mad."
- from an aircraft engineer—"Less new things being talked about than at previous meetings. And there is too much emphasis on computer usage rather than on theoretical and developmental aspects."

One of the featured speakers at a conference luncheon, Dr. Edward (H-Bomb) Teller, caused chuckles with this poser: would two computers playing chess cheat or stick to the rules of the game?

But all feedback on the meeting was not negative. Our man was impressed by the working computers in the booths and the way they were demonstrated, by the liveliness of some of the papers, and by the session on RCA's new BIZMAC system. Papers were given on BIZMAC purposes, application, functional organization, characteristics, and programming. Some people, however, opined that BIZMAC, while advanced in input and output, may be endowed with an imbalance between memory and computing capacity. And all are concerned with the large amount of people needed to run it.

"All in all," says our western editor, "the conference reported a lot of hard work, a lot of good engineering, and so forth—but nothing startling and new."

Chicago, Jan. 25-26

Today's broad fever-pitch interest in process control was never better demonstrated than in this intense two-day conference in one of the bright new buildings occupied by Armour Research Foundation on Illinois Tech's sprouting South-Side campus. Over 250 came from 21 states and Canada—and the bulk of them were from the control-hungry user industries: meat packers, steel makers, drug houses, paint manufacturers.

The program did an effective shotgun job of covering group interests in the short time. It dwelled on

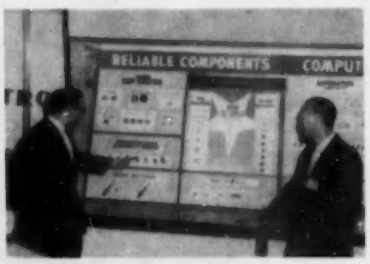
SOME OF THE WESTERN COMPUTER SHOW BOOTH HIGHLIGHTS

BURROUGHS E 101 and its blonde operator got much attention. She was taught to solve three-degree simultaneous equations in a few minutes on opening day.

LITTON-20 DDA, a $10,000 desktop machine, had good talkers to explain away its 20 integrators and one part in 250,000 accuracy. The unit is at right on table.

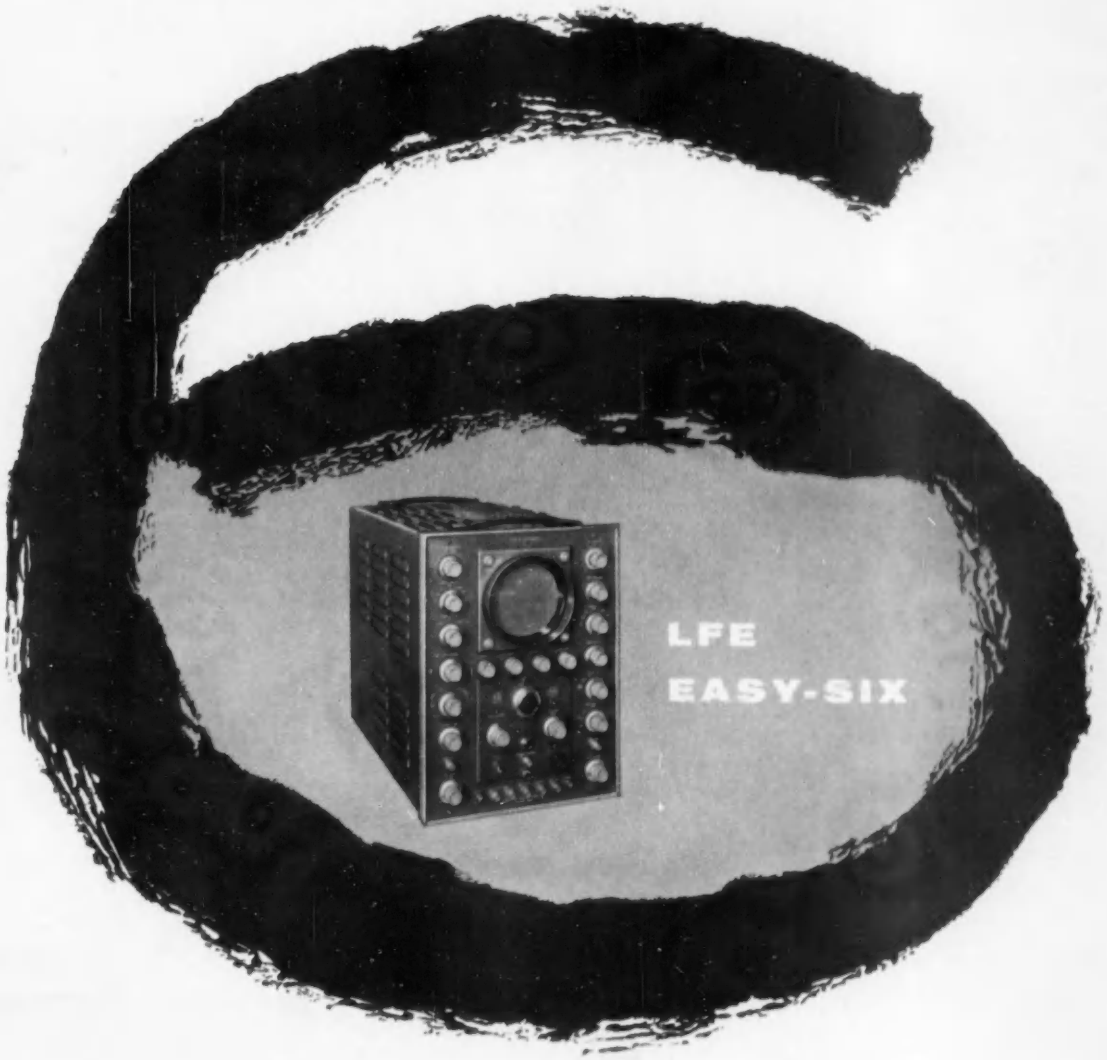
BECKMAN'S *EASE* proved to be an impressive 100-amplifier analog computer. The only other analog unit on display was Electronic Associates' 12-amplifier model.

LIBRASCOPE LGP-30, just unveiled last November, also pulled in the onlookers. The console-size unit packs a 4,098-word capacity and a 3,600-rpm access speed.



SPRAGUE COMPONENTS—magnetic, transistorized, subminiature—formed a revealing display of how "old line" firms are joining the computer bandwagon.

HUGHES AIRCRAFT provided an offbeat but vigorously attended exhibit for the show: a working display of fire control that will fend off sneak air attacks.



One basic oscilloscope for almost any job . . .

USING PLUG-IN ADAPTERS

These six Plug-in units available for use with this instrument effectively provide a family of scopes, tailor-made for special applications as well as for general purpose precision laboratory use.

1. Model 1400 Basic Unit — for general purpose use
2. Model 1401 Sweep Delay — wide range, 1 μsec to 0.1 sec
3. Model 1402 Video Switch — for dual trace presentation of two inputs
4. Model 1403 Gated Marker Generator — for direct time measurements
5. Model 1404 TV Trigger Shaper — for television applications
6. Model 1405 Long Sweep Generator — for sweeps as slow as 5 sec/cm

And with *all* of these Plug-in Adapters you get the advantages of the 411's precision Y-Axis Amplifier with these outstanding performance specifications:

a. Sensitivity — 20 mv/cm peak-to-peak to both dc and ac with 6000 volt accelerating potential

b. Frequency Response — dc to 10 mc

c. Transient Response — Rise time; 0.035 μsec

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With an output of ±100V the K2-X is priced at $24. The K2-W at $20. puts out an ample ±50V with less power needed.

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The Model HK Operational Amplifier in the standard version offers 10 K2-W Amplifiers for analog calculations of infinite variety. A stabilized HK using K2-X and K2-P *"paired"* plug-ins provides greater output plus stability. The *standard* HK with 10 K2-Ws is $360. The *stabilized* HK with 5 of above "pairs" is $555.

Supplied also in a self-powered version as the compact Model HKR Operational Ten-fold, all manifolds can be purchased in either *standard* or *stabilized* forms or in other combinations.

For rapid utilization of the HK or HKR, Model K- Modular Assembly units are offered either in kit form or assembled as Adder, Coefficient, Differentiator, Integrator or Unit-lag Passive Operational Plug-ins. Prices furnished on request.

One of the many "power packages" from GAP/R is the Model R-100 Regulated Power Supply, conservatively rated at 100 ma, ±300VDC, and modestly priced at $130.

Indicated below are two possible arrangements whereby your laboratory or engineering office can obtain a basic computing facility at minimum cost.

20 OPERATIONAL AMPLIFIERS Plus Regulated Power		10 STABILIZED AMPLIFIERS Plus Regulated Power	
2 MEs (with 20 K2-Ws)	$720.	2 MEs (10K's + 10 P's)	$1110.
1 R-100 Power Supply	130.	2 R-100 Power Supplies	260.
	$850.		$1370.

For more details and other information please write to:

George A. Philbrick Researches, Inc.
230 Congress Street, Boston 10, Massachusetts

GAP/R

WHAT'S NEW

pneumatic and electric actuators, automatic weighing and counting, scanning and logging, and the economics of process control. But the most informative sessions had to do with data handling systems. Three speakers reviewed the technical and economic advantages of this new adjunct to process control–all warning that such systems should not obtain data for its own sake . . . but are only feasible if the data are put to rapid use.

Panellit's Al Sperry was most articulate. He commented that even the most elaborate equipment available today yields little more than lower level decisions–that is, simply information about the process itself rather than information about the process in relation to the overall higher level management operation. Thus he feels that the challenge ahead involves faster closing of the information loop around management-decision functions. To reduce the time scale of the process, operator, technical staff, and management in decision making, says Sperry, will require an unrelenting use of the best equipment available and quick adoption of promising new techniques and developments in the field.

Dallas, Jan. 19-21

Computer simulation as sole theme for a national meeting got an auspicious vote-of-confidence in this throbbing Texas metropolis. Over 400 engineers came to hear 35 papers ranging in content from the analog simulation of missiles, tanks, and torpedoes, to an arrangement for studying human dynamics in a closed-loop system. Significantly, there were also five papers dwelling on the use of digital techniques in simulation. The conference was sponsored by the Dallas and Fort Worth sections of the IRE, the North Texas section of AIEE, and the Dallas-Fort Worth chapter of the Association for Computing Machinery.

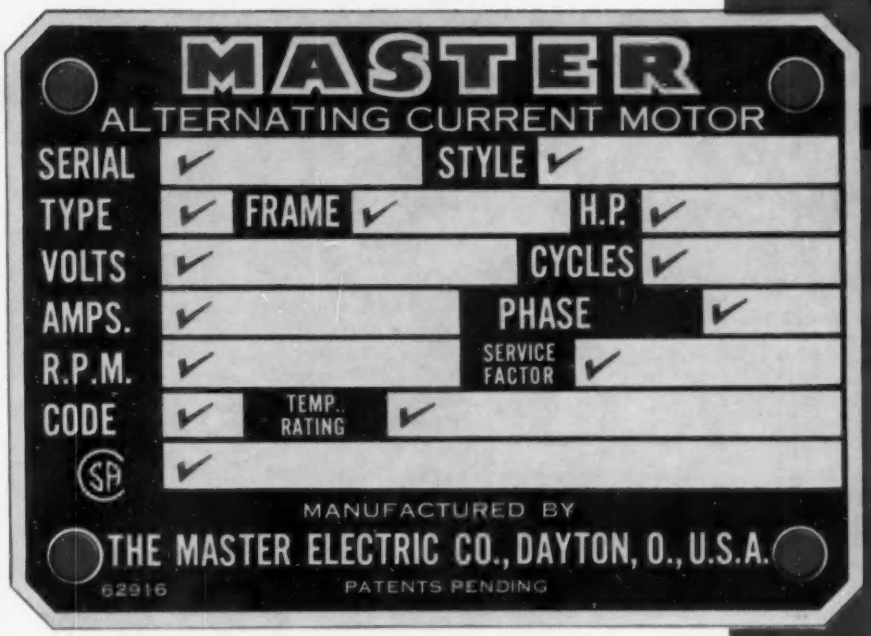
REAL SPEAKERS ON SIMULATORS

Three of the Texas Simulation Conference speakers (l to r): Julius Tou, U of Pennsylvania ("High Accuracy Operational Digital Simulation"); C. C. Calvin, Chance Vought Aircraft ("Repeatable Generation of Noise with a Masked Cathode Ray Tube"); H. E. Blanton, Hycon Eastern ("Performance Requirements for Flight Tables").

YE OLDE YANKEE INSTRUMENTS FAIR

Things may be staid in old Back Bay, but when the Boston chapter of ISA decides to put on a regional show and symposium, it does it up as brown as the proverbial local baked beans. The picture shows just a few of the 59 exhibitors who flocked to fill space at the Sherry-Biltmore Hotel on Jan. 10-11. But it does not hint at the amazing attendance: 1,582 registrants to vend and look, and 400 serious note-takers at the symposium on analysis instruments and process control. Owen C. Jones, exhibit chairman, says more space will be needed for future Yankee Instrument Fairs.

Write your own ticket—



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- Electromechanical regulator, unlike usual magnetic voltage stabilizer, introduces no distortion or phase shift

Here at last is the ideal solution to the disturbing problem of harmonics and low frequency noise appearing in 115 V., 60 cps power sources. In one compact package, every laboratory can now obtain *both*

1) distortion-free, regulated power when needed, and simultaneously

2) a large supply of electromechanically regulated power for applications where normal line distortion is tolerable.

In addition to its general laboratory utility, this instrument is ideally suited for preventing instability and inaccuracy in a.c. computer system nulling operations. Many other applications. 230 V. model also available. Immediate delivery. $1,689 f.o.b. Carlstadt, N. J. Write for details.

Component & Instrument Department

ELECTRONICS DIVISION
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WHAT'S NEW

And while it was experimentally patterned after the "Cyclone" and "Typhoon" symposia sponsored by the Navy in New York and Philadelphia in 1951, '52, and '53, its obvious success suggests that the Simulation Conference will now become a national affair. All papers will soon be published in *Proceedings of the IRE* and can be ordered from the conference treasurer, Prof. F. W. Tatum, EE Dept., Southern Methodist University, Dallas.

CONCLAVES TO COME

Cleveland, June 11-29

Dynamic analysis is like Marilyn Monroe. You hear a lot about it, but you rarely get the opportunity to personally sift fact from fancy. Well, now's your chance. For although Case Institute hardly offers the lure of Marilyn in its forthcoming summer study course in "Process Control Theory with Frequency Techniques", it does give the live control engineer the next best thing: an opportunity to get a rigorous dose of training in use of the tools of systems engineering. The course Prof. Don Eckman and Irv Lefkowitz of the ME Department have set up is no snap. It requires an engineering degree and includes formal lectures, lab experiments, and round-table discussions. The $275 tuition fee—covering books, lab materials, etc.—is a real investment for those control engineers who plan, some day, to put the new tools of their trade to work. Write Don before April 27, 1956, for admission.

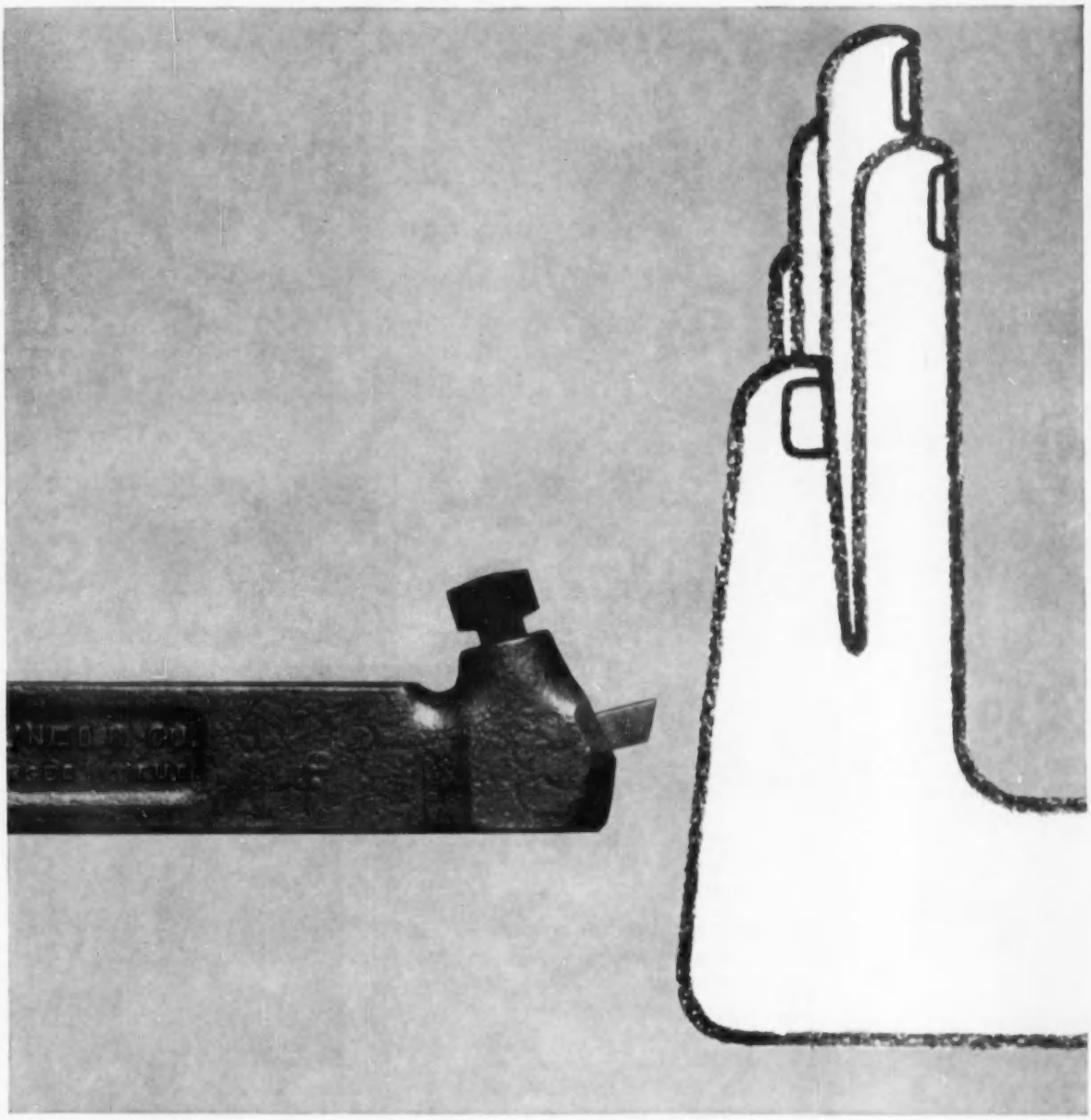
Cambridge, June 18-29

MIT will also be offering some special summer courses to control engineers who wish to brush up on certain phases of their art. One such two-week program is on "Switching Circuits" and will be presided over by Prof. Samuel E. Caldwell and Asst. Prof. David A. Huffman, both of the EE Department. The course will stress basic concepts and principles of switching and logical design. It will include switching algebra, graphical and numerical aids to network simplification, multiple-output networks, sequential circuit synthesis and memory requirements. No previous experience in mathematical details of switching circuits is required. Write the Summer Sessions Office, MIT, Cambridge 39, for details.

ISA MEETING KEYNOTERS

Gordon Volkenant's props for his forthcoming stint at the ISA-Wilmington symposium on Control Systems Engineering look intriuging. The former associate director of research for Honeywell—with his comely assistant—is guaranteed to jolt onlookers off their seats when he lecture-demonstrates "Mr. Electron—Automation's Greatest Master Minder". Four other less heady but equally rewarding papers on systems, devices, actuators, and safety, round out the program. It will be held on April 25, 1:30 pm, at the Du Pont Hotel, Wilmington.

Dr. Elmer W. Engstrom, Senior Executive Vice President of RCA, has been appointed General Chairman of the 11th Annual Instrument-Automation Conference and Exhibit, sponsored by ISA in New York City's spanking new Coliseum, Sept. 17-21, 1956. Engstrom, an electrical engineer, is well known for his direction of RCA's Laboratories. All signs indicate that he will head up a spectacular meeting. As of March 1, most booth space had been sold—hence roughly 150,000 sq ft will be occupied by exhibits. Over 30,000 are expected to attend.



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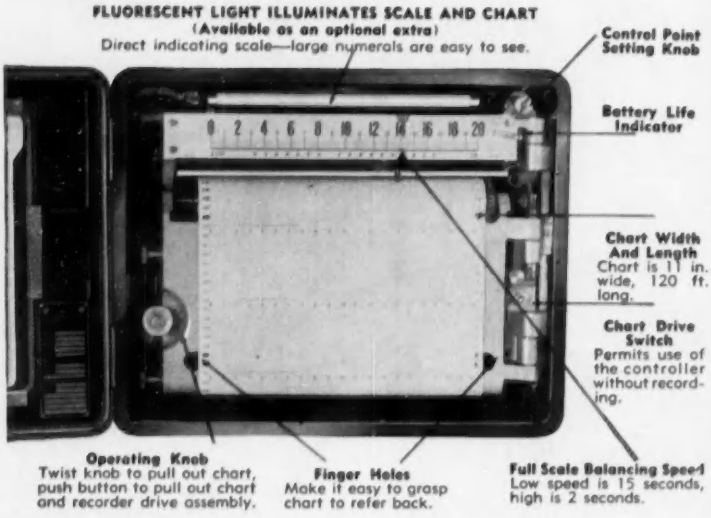
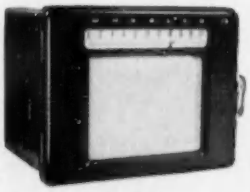




Accessibility and ease of adjustment were primary design considerations when Wheelco developed the new Series 8000 Potentiometer-Recorder. While every Wheelco instrument is built to function with maximum accuracy and minimum maintenance, this new null-balancing type electronic recorder was designed to be especially easy to use.

The front cover swings open 180 deg, thus permitting the chart drive to swing out a similar 180 deg, making the internal mechanism accessible. Wheelco Series 8000 Potentiometer-Recorder is available to measure, indicate, control, and give permanent record of variables such as temperature, speed, strain, hydrogen ion (pH), and any other quantities which can be resolved into electrical signals.

Send for new catalog which gives complete technical information on this latest Wheelco instrument.

WHEELCO INSTRUMENTS DIVISION
Barber-Colman Company

Dept. D, 1548 Rock Street, Rockford, Illinois
BARBER-COLMAN of CANADA, Ltd., Dept. C, Toronto and Montreal, Canada

WHAT'S NEW

Madison, April 19-20

Ralph Smith, Institute Coordinator at the University of Wisconsin Extension Div., will be running this two-day study-review on the control of manufacturing processes. The application of specific controls to certain processes will be the main theme, but there will also be a general discussion of processes that lend themselves to automatic control and some possible means of controlling them. Fee for the course is $20.

Honeywell-Raytheon Offspring Unfurls Its Entry into the Big Computer Field

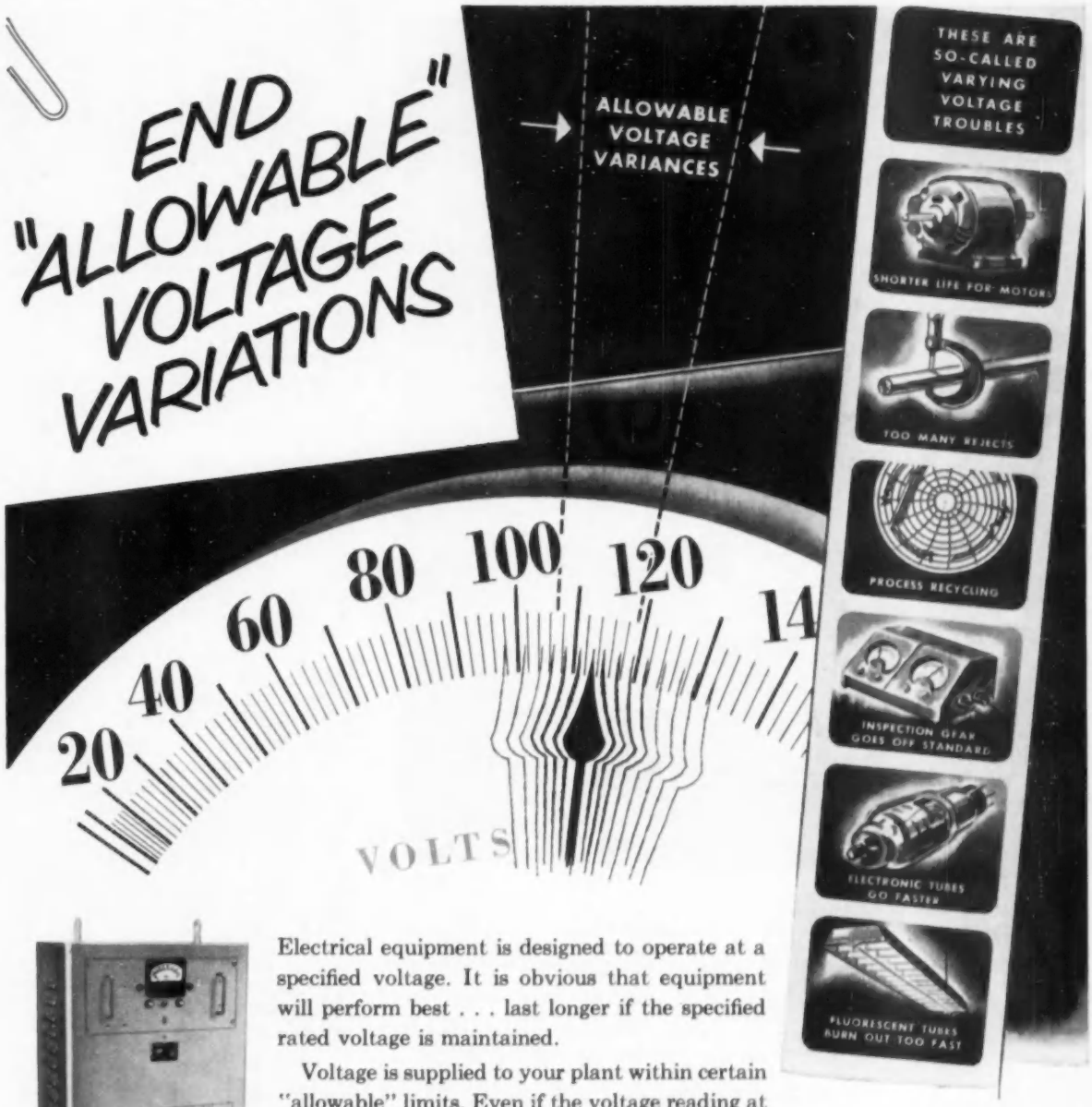
Most unusual feature of the new Datamatic-1000 is this magnetic tape file. Tape used is 4 in. wide, mylar coated, and holds, in 2,700 ft, as much data as a half-million punched cards.

It's hard to believe, but less than a year after its birth the still-bouncing Datamatic Corp. has come up with a testimonial to the talent of its parents (Minneapolis-Honeywell, 60 per cent —Raytheon, 40 per cent). The proof? Simply the first full-dress model of a big, classy $1.5-million business data-processing machine that could well be a prime dark horse contender in the 1957 computer sweepstakes.

Aside from its professional design and handsome styling, Datamatic's new system lays claim to the front of the field on several counts:

▶ its storage files use a 31-channel

END "ALLOWABLE" VOLTAGE VARIATIONS



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Electrical equipment is designed to operate at a specified voltage. It is obvious that equipment will perform best . . . last longer if the specified rated voltage is maintained.

Voltage is supplied to your plant within certain "allowable" limits. Even if the voltage reading at your doorstep is right on the button, voltage variations occur within the plant.

STABILINE* Automatic Voltage Regulators end voltage variation headaches. They maintain constant specified voltage to voltage-sensitive equipment regardless of line voltage fluctuations or load changes. There is a STABILINE to fulfill the needs of most applications. Let us give you more facts.

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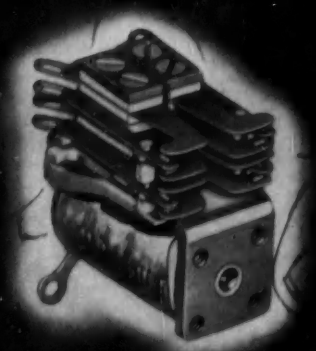

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ADVANCE TQ
MINIATURE RELAY

Only .94 cubic inches in size... only 1.2 ounces in weight—yet this new ADVANCE TQ telephone type carries 3-amp. loads in the 4PDT combination. It's available up to 6PDT, and with class "H" insulation such as Teflon, ceramic and silicone.

It's extra efficient, too, having only one air gap in the magnetic assembly. No hinge pin to wear out—there's a beryllium copper retaining spring which holds the armature rigidly in place in 3 major axes. With this construction, plus the use of cross-bar contacts, all alignment problems are eliminated.

Insulation is inorganic, and the coil requires no impregnation or filler. Hence there is no gassing or bubbling to cause contact contamination. The TQ relay is mechanically secured throughout—a feature that adds materially to its high efficiency.

EXCELLENT PERFORMANCE

The unit operates on 90 milliwatts or less, and hence can be classed as a sensitive type. Withstands 10G vibration (10 to 55 CPS). Ambient temperature ranges: −55°C to +85°C with standard coil... with Teflon coil, −55°C to +125°C. Life expectancy: 1,000,000 cycles with cross-bar contacts. Available in open and hermetically sealed types. Write for full description of the ADVANCE TQ.

ELECTRONICS DIVISION
ELGIN NATIONAL WATCH COMPANY
FOR RELAYS: 2435 N. Naomi Street, Burbank, California

WHAT'S NEW

mylar-coated tape that is nontearable, reversible in action, and holds ten times more information than conventional 1½-in. tape.

▶ its large residual capacity and its flexibility permit it to be used economically for computer sorting of related data, thus skirting the usual mechanical sorting.

▶ its input system is able to feed, translate, edit, and arrange all data on 900 punched cards per min—printed output is 900 lines per min.

While its revved-up, oversized tape-handler seems to be the big asset, Datamatic engineers maintain that all aspects of the system's design are paces ahead of the best in competitive equipment today. They stress the "balance" that they have built into the system—the ability of access speed to match the speed of arithmetic processing—and the fact that this "balance" can actually mean performance gains many times greater than the basic tenfold improvement offered by the reversible, wide-tape file.

No machines have been sold to date. But three companies already have sent technicians to the Newton Highlands, Mass., plant of Datamatic to be trained in the design and programming of the new system. However, the first complete machine, to be put to work next fall, will churn away on Raytheon and Honeywell problems. And by the time system No. 2 is ready, all "bugs" are expected to be routed for the initial clean sale.

All Around the Business Loop

▶ An Air Force officer attending a recent government exhibit in New York City gave an interrogator a clue to what he might find in a plant that produces instruments for aerial research. Such a plant has been opened in Los Angeles by **Fairchild Controls Corp.** of **Fairchild Camera & Instrument Corp.** Sherman Fairchild, board chairman, resurrected the question and its answer in telling the press about FCC's new home for its **Potentiometer Div.**

"Suppose I lived in a house in that city," the interrogator said. He indicated a city on a strip of film, 200 ft long by 9 in. wide, that had taken a 490-mile-wide bite out of the U. S. and ripped a swath from Los Angeles to New York, a distance of 2,700 miles. "What," he asked, "could you tell me about it from 40,000 ft up?"

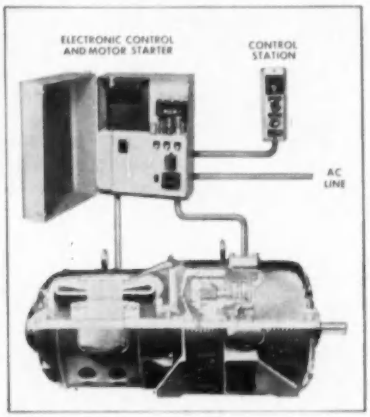
DYNAMATIC® ELECTRONIC CONTROLS

Can Solve Your Adjustable Speed Problems

Dynamatic electronic controls with their simplicity, low maintenance, easy accessibility, and small space requirements, when used with Dynamatic Eddy-Current Drives, provide the solution to most adjustable speed drive problems.

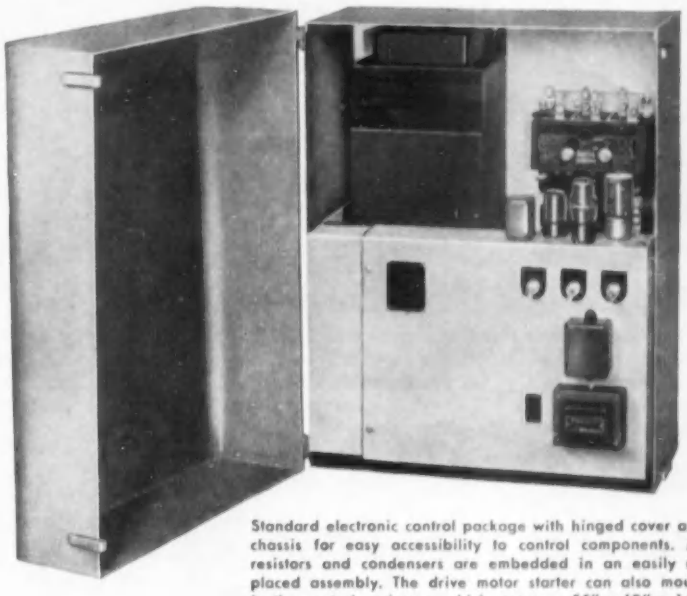
The excitation required by Dynamatic eddy-current equipment is of very small magnitude compared to the drive capacity. For example, a 440 watt control is capable of controlling the torque or speed output of a 400 HP drive. Control and excitation power is taken directly from AC lines without the need of cumbersome and complicated convertors, with their installation, ventilation, and maintenance problems.

Since the control elements have a very high amplification factor, even the largest couplings may be easily and conveniently controlled with small adjusting potentiometers.



The small illustration shows the minimum of typical components necessary to obtain adjustable speed with Dynamatic eddy-current equipment. Speed regulation requirements on the order of 1/10 of 1 per cent of drive top speed are easily and economically accomplished with suitable control modifications. With low powered reliable electronic components, requirements to suit almost all drive problems are easily met without appreciably increasing the cost or size of the control components.

The following outline of operation will indicate the many advantages of this Dynamatic control equipment.



Standard electronic control package with hinged cover and chassis for easy accessibility to control components. All resistors and condensers are embedded in an easily replaced assembly. The drive motor starter can also mount in the control enclosure, which measures 25" x 19" x 14".

Direct current excitation applied to the Dynamatic Drive coil modulates the strength of the magnetic fields and consequently, the amount of torque developed at any rate of slip between the rotating input and output members. So that the drive may satisfy load and speed demands, this direct current must be varied automatically.

Because of the drive's small power demands, rectification of easily available alternating current to direct current is a simple procedure. A gas-filled thyratron tube is all that is needed to accomplish the conversion from AC to DC. A rectifier used in conjunction with the thyratron tube, plus the highly inductive eddy-current drive coil, provides a smooth flow of direct current as required by the drive.

To obtain desired performance, a means of varying the amount of current to the drive coil must be provided. The thyratron tube provides this function in that the grid of the tube, influenced by an AC rider wave imposed upon the DC grid voltage, permits a smooth change in drive coil voltage from zero up to the available maximum.

A permanent magnet alternator, driven by the output shaft of the Dynamatic Drive, generates a voltage in direct proportion to speed. This voltage directed to the electronic control is utilized to maintain pre-set speed. With a reduction in load, speed tends to increase, but the generator signals the control so that the drive coil current decreases, slowing down the unit. Conversely, should the load increase, the drive tends to slow down so that the generator signal to the electronic control automatically increases the current, permitting the drive to return to the pre-set speed.

Speed and load (current) control are two of the standard types of electronic controls available. Because of the almost unlimited uses and adaptations of electronic components, many operations can be conveniently controlled, such as tension, acceleration, braking, threading, jogging, speed matching, and many others where an electrical signal can be fed to the control equipment.

Send for our 16-page Illustrated Bulletin on Electronic Controls

EATON MANUFACTURING COMPANY
DYNAMATIC DIVISION
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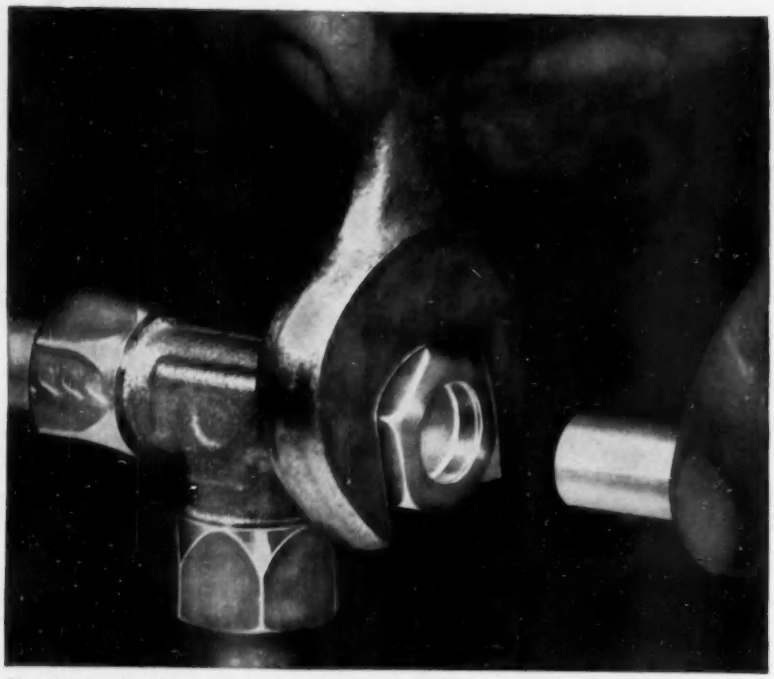

Simply push, then tighten! Anyone can quickly install all-new, *lightweight Intru-lok* tube fittings . . . the proven Parker 3-piece flareless design. Just insert the tube, then tighten the nut with a regular wrench . . . for a leakproof, vibration-proof joint. Made of brass for copper or nylon tubing. Send for complete details in Catalog 4324.

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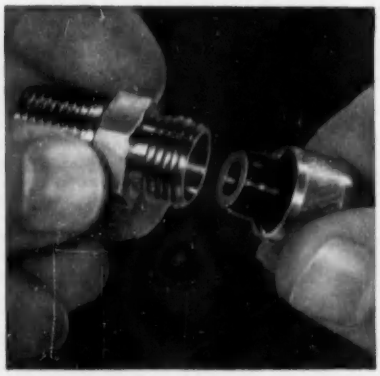

For soft plastic tubing you use knurled nut and expander insert with new *Intru-lok* body. Joints can be disconnected and reassembled. Complete details in Catalog 4324. Send for it.

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Parker
Hydraulic and fluid system components

WHAT'S NEW

The Air Force man, Fairchild said, took a deep breath and let go: "We could tell pretty accurately the height of your house, what it was constructed of, and the relative age of your community. We could make a good guess on your own economic status. We could tell whether you used a rotary-type lawn mower to cut your grass, whether you had a telephone and an underground septic tank—and probably even describe the clothes hanging on the line in your backyard."

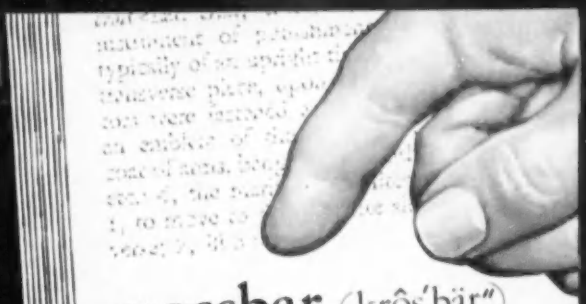
The Air Force man could also have informed the citizen that if the grass for the rotary mower was just camouflage, one species of film could have revealed that, too, by detecting the presence or absence of chlorophyll. And that if he was fortunate enough to have uranium or other minerals under his land, instruments like the magnetometer and the scintillometer would have told him so.

All this, of course, would not be possible without the "systems concept", Fairchild declared. "It involves teaming the camera with electronics and other methods of detection and integrating the whole with other weapons systems." He revived these words of Lt.-Gen. Thomas S. Power, commander of the Air Force's Air Research & Development Command: "Preceding World War II, military arsenals were military institutions. Today, the Air Force arsenals are American industry. In order to function as a team, there must be mutual confidence and a wide exchange of technical information and knowledge."

Fairchild's company is wasting no time in strengthening this philosophy. At the open house it unwrapped a brand-new pressure transducer, the first in a line of components being developed by the Potentiometer Div., and it showed some of the work of its other divisions: gear for aerial inspection; oscilloscope recording cameras and medical cameras; a mock-up of a motion-picture camera that will take 5,000 frames per sec; and an animated display that depicts past geophysical explorations and shows how electronic equipment goes to work on the surface of a terrain.

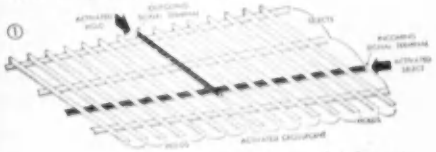
To impress his point, Fairchild detailed the duties of his company's new Nuclear Instrumentation Dept. Among them: development and production of radiation monitoring equipment, control drive rod mechanisms for atomic reactors, neutron detectors, and associated temperature, pressure, and flow controls. And he threw an admiring finger at Milton Chaffee (see March

IT WILL SAVE YOU TIME AND MONEY TO ADD "CROSSBAR" TO YOUR AUTOMATION VOCABULARY

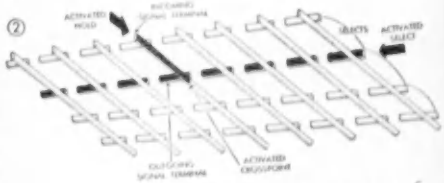


crossbar (krôs'bär")

The most modern, compact, fast, and economical means of concentrating hundreds of relay or switching operations for practically any automatic control, computing, reporting or sequential sampling operation.



The basic Crossbar principle which permits any of several incoming circuits to be connected to any of several output circuits is illustrated above. This switch actually can connect any of 60 circuits, 3 at a time, to any of 75.



The drawing above shows a means of switching one incoming circuit to many possible outgoing circuits. This type of switch can easily be adapted to switch one circuit to as many as 936 circuits.

Here is why Crossbar takes the place of Relay Tree in your automation vocabulary: With the Kellogg Crossbar several switching operations can be carried on independently at the same time . . . entire switch can be mounted in drawer-type frame for easy inspection . . . contact material is palladium (or gold) . . . any crosspoint can be activated in less than 50 milliseconds.

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Kellogg engineers will show you how Crossbar advantages will work for you. Saves design time.

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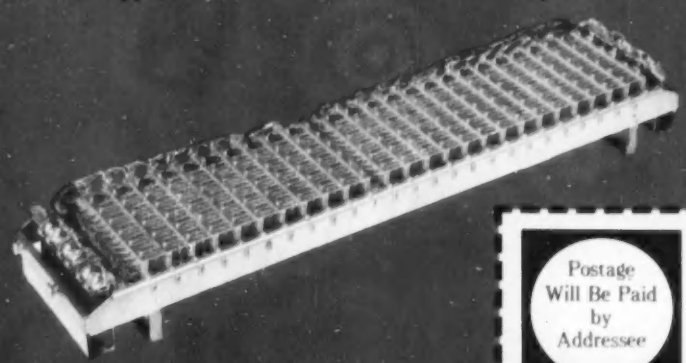
Kellogg Crossbar has been adapted to a wide variety of industrial applications.

ECONOMY

Kellogg Crossbar:

- Requires practically no routine maintenance
- Is equivalent to a bank of relays, assembled, mounted, and partially prewired
- Uses less hardware
- Uses fewer coils
- Consumes less power



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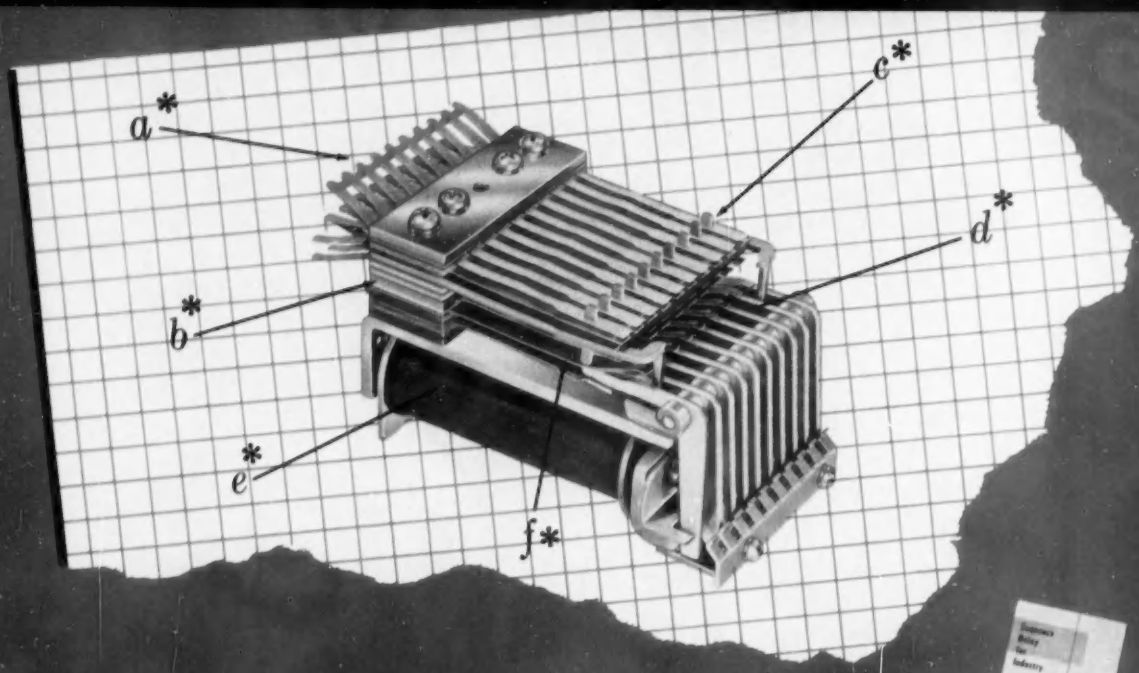

We have been making and improving relays for more than 58 years. The use of these relays in our own equipment has helped to make Kellogg the leader in the independent telephone field.

A typical example is this sequence relay, "the Kellogg Magnetic Impulse Counter." This unique counter eliminates sliding contacts, mechanical rachets, etc. . . . the counting sequence is controlled electromagnetically, with relay-type contacts used throughout. Production advantages include: simplified circuitry, reduced size, lower cost and longer life.

You can save design time and cut production costs because our intimate experience as a relay-user, as well as relay-maker, enables us to develop relays that are rated to meet your requirements . . . build them to stand up in your equipment, for a lifetime of service.

* *For the A.B.C.'s of the Magnetic Impulse Counter and other Kellogg relays use the attached card to send for this Kellogg Relay Bulletin.*

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issue, page 22), whose appointment as director of electronic and systems research is further proof that Fairchild is out to fulfill its part of the "systems concept".

The 25,000-sq-ft plant at Los Angeles cost about $500,000 and sprawls over nearly seven acres. It's one of the main factors supporting Fairchild's prediction of a 50 per cent increase in potentiometer sales this year.

► There's a different kind of drama in the latest move by **IBM.** Here, too, if you put your ear to it, you might be able to detect the clicking of little gadgets (for IBM also has a fair share), but don't be alarmed if all you hear is thunder of giant footsteps. You're listening to the leviathan of the calculator field making the greatest regional expansion in its history.

Item: A new 13-story office building and data processing center in Los Angeles. Here, by mid-1957, one Type 704 calculator, one Type 705, and at least one Type 650 will occupy part of the 85,000 sq ft of space IBM has reserved for itself. They'll be available to clients on an hourly charge basis. One-third of the company's West Coast district sales staff will be located here, too. Altogether, the payroll will total 600.

Item: A six-story office building in San Francisco, which should be functioning by the time this issue is out. On the four floors occupied by IBM are a service bureau containing data processing machines and smaller equipment, classrooms and other educational facilities, and another third of the West Coast district sales office. Personnel here comes to 300.

Item: New manufacturing, engineering, and educational facilities at San Jose. This section will draw 1,500 employees to its 400,000 sq ft when it opens in the fall. One of its principal projects: work on data processing machines with random access.

Item: A new office building in Santa Monica. More than 150 already are at work in this two-story, 11,078-sq ft-structure.

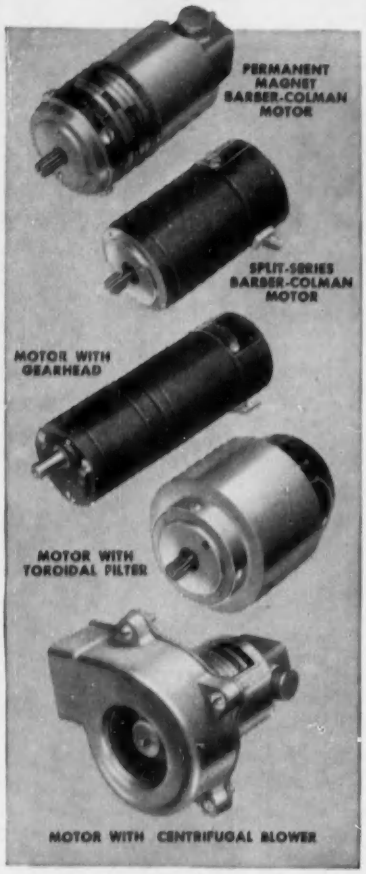
Item: Data processing centers in Portland, Ore., and Seattle. These facilities give the Pacific Northwest its first real taste of electronic data processing machines. A Type 650 is already at work in Portland. Seattle, where another goes into action in June, is home for the rest of the district sales staff.

IBM has also established, within its Research & Development Dept., an independent research organization under Ralph L. Palmer, formerly di-

BARBER COLMAN

d-c motors

compact, powerful high quality for a wide range of applications



Looking for a d-c fractional hp motor of unusually high quality, high dependability? Specify Barber-Colman, the *versatile* line of small motors in both permanent magnet and split series types . . . in various mountings and speeds, and outputs up to 1/10 hp. Ideally suited to power electro-mechanical actuators, switches, blowers and programing devices. Barber-Colman small d-c motors are also available with lightweight radio noise filters to meet radio interference requirements of USAF. They are ideally suited for use as tachometer generators. Whatever your problem involving small motors, consult Barber-Colman Company for an expert solution.

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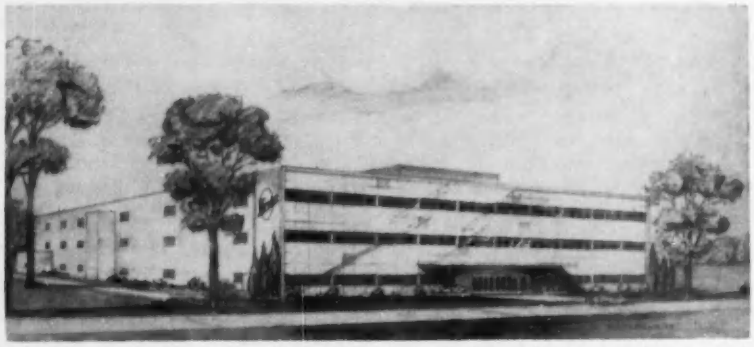
WHAT'S NEW

CONTROL A-BUILDING—WEST AND EAST

Fairchild plant in L. A.: potentiometers for picking out a lawn mower from 40,000 ft.

This L. A. job is the big one: but others figure just as prominently in IBM plans.



240,000 sq ft for Kearfott in Little Falls, N. J.: all the works to go under one roof.

rector of engineering. Nucleus is a new Product Development Laboratory at Poughkeepsie, N. Y., headed by Horace S. Beattie, who has been manager of the Poughkeepsie Engineering Laboratory. Object of the move: "to develop business machines of the future".

Building activity is pulsing through other sectors of the business loop, too. Evidence:

▶An engineering-sales building in Little Falls, N. J., for **Kearfott Co., Inc.** Offices, laboratories, pilot plants, and other departments will be centralized in the 240,000-sq-ft structure to be completed early next year. It will increase Kearfott's working space to 600,000 sq ft.

▶A $20-million expansion program by **Lockheed Aircraft Corp.'s Missile Systems Div.** (see February issue, page 24). Lockheed has joined forces with **Stanford University** in a project that calls for a new dual headquarters for missile production at Palo Alto and

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Opens the way to new advances in space-saving audio design

A new achievement from Philco laboratories, the M-1 "Audio Mite" Transistor is smaller than any transistor now in production! It retains all the desirable electrical characteristics, all the mechanical features, all the performance of the Philco 2N47 . . . the transistor proved in the field to be without equal in hearing aid applications. The "Audio Mite" is hermetically sealed in metal the unique Philco way . . . the design that has earned a reputation as the most reliable hermetic seal in the industry. A wide new field in low level audio applications is opened to design engineers by this tiny PNP alloy junction transistor.

For complete technical information write to Dept. CE-2

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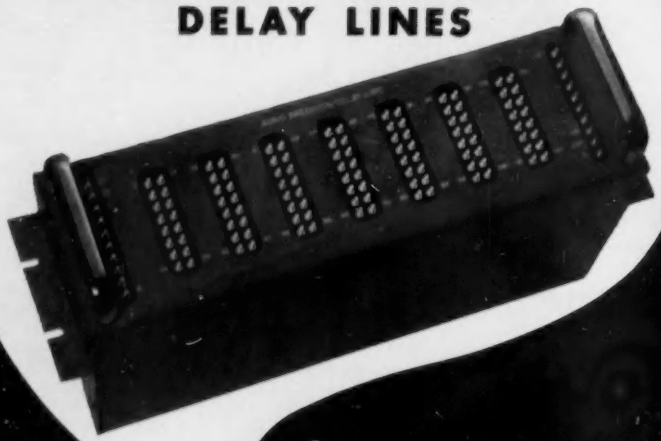

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New EPSCO 5000 microsecond Precision Delay Lines Model DL 0510-400/125 are specifically designed for use in precision analog computing, auto-correlation, function generation and sonic and sub-sonic applications. These units have found application in the study of speech wave-forms, wow and flutter of tape transport mechanisms, sonar returns, sonar ranging and servo analysis.

They feature extremely long delay (which may be further extended by cascading several units), low attenuation and excellent phase linearity over a wide range of frequencies.

Design is based on M-derived techniques and employs very high-Q toroidal inductance assemblies and ultra-stable capacitors. Taps are brought out on the front panel by heavy double-turret lugs for easy accessibility.

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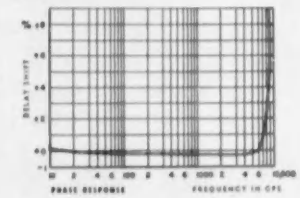
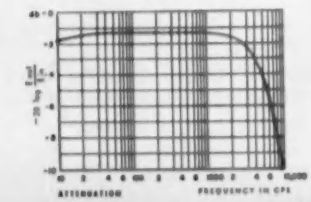
CHARACTERISTICS AND SPECIFICATIONS

Overall Delay	5000 μs ±1%
Characteristic Impedance	510 ohms*
Number of Taps	125
Delay between Taps	40.0 μs ±1%
Attenuation including insertion loss	Better than 3db at 4kc Better than 6db at 7kc
Low Frequency Insertion Loss	1.7db
Cutoff Frequency	9.5kc
Phase Linearity	±0.2% up to 6kc ±1% up to 8kc
Size	19" x 5¼" x 9" for relay rack mounting
Weight	35 lbs.

*Also available with 470; 600 and 1,000 ohm impedance





EPSCO INCORPORATED

588 COMMONWEALTH AVE BOSTON 15, MASS

WHAT'S NEW

Sunnydale, Calif. First on the agenda are two Stanford laboratories and the initial Sunnydale construction. Cost: $7 million. The present missile base at Van Nuys, Calif., will continue in operation for some time.

▶ An electronics plant in Denver for **The Ramo-Wooldridge Corp.** The new development, whose 172,000 sq ft will allow for future expansion, will have as a neighbor **Glenn L. Martin's** ballistic missile plant, also a-building. Ramo-Wooldridge will concentrate on military systems for the time being, later will take on commercial work.

▶ A new home for **Reeves Instrument Corp.** This move by Reeves is at once expansive and collective. In a refurbished $5-million plant in Mineola, N. Y., are concentrated all Reeves' research, development, and production programs previously scattered about Roosevelt Field. Working space has increased 30 per cent to about 500,000 sq ft.

▶ A $3,300,000 headquarters building in Downey, Calif., for the **Autonetics Div. of North American Aviation, Inc.** This will be the hub for other Downey developments, some already completed. They'll share Autonetics' work in computers, aircraft fire controls systems, and automatic navigation systems.

▶ Larger quarters in Richmond Hill, N. Y., for **General Transistor Corp.** This move, from the former base in Jamaica, means 200 per cent more manufacturing space.

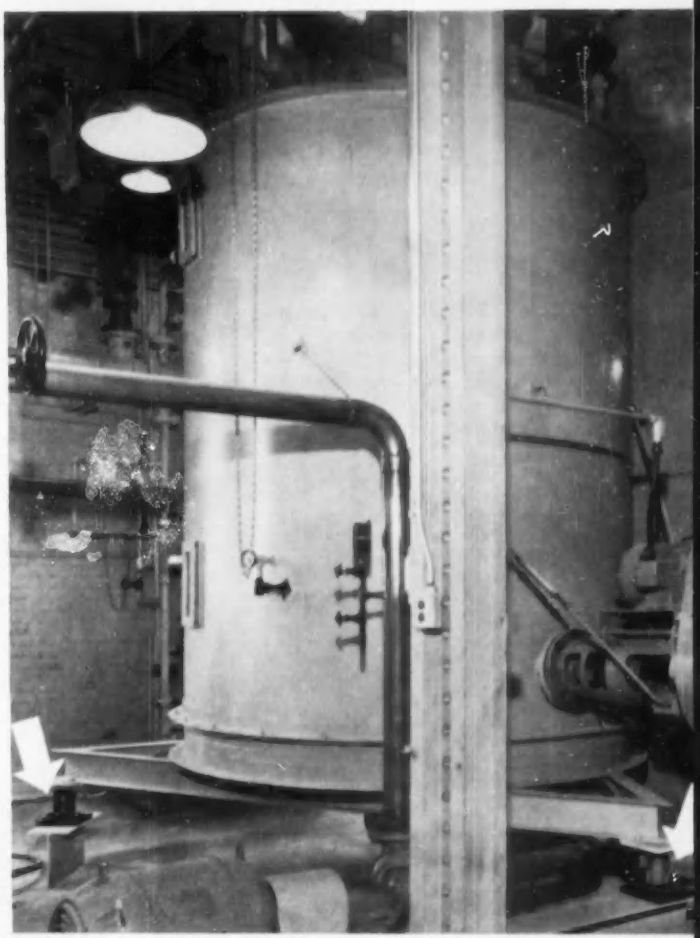
Among other developments around the business loop:

▶ With the formation of an **Industrial Computer Section** at Electronics Park, Syracuse, N. Y., **General Electric** moves into the industrial computer field. To be integrated into the new section are specialized engineering and military projects and all other aspects of the company's widespread computer work. An advanced engineering development program is already shaping under the section's new general manager, H. R. Oldfield, Jr., who has been manager of the **Microwave Laboratory** at Palo Alto, Calif.

▶ **Sperry Gyroscope Co.** has been awarded a $7½ million Air Force contract for production of advanced airborne radar systems. The order, which follows developments of these lightweight (150-lb) units by barely a year, calls for an undisclosed number for troop transports and cargo planes.

▶ **Minneapolis-Honeywell Regulator Co.** has set up a Viennese subsidiary, **Honeywell G.m.b.h.,** to provide sales, engineering, and service to Austria.

Baldwin SR-4® system controls mixing to .1% repeatability



In a west coast processing plant, liquid sugar is mixed automatically by a Baldwin SR-4 system whose accuracy is within .1% repeatability.

Here's how it works. A 2,500-gallon mixing tank and 10,000-gallon storage tank stand vertically on triangular frames whose corners rest on Baldwin SR-4 load cells (photo at right). These strain gage type cells measure tank weight changes and transmit electrical signals to a Baldwin indicator-controller (photo above) which shows total weight of tank contents in pounds.

To start the process, dry sugar and water valves are opened manually; from there on mixing is automatic. When the load cells signal that predetermined proportions have been reached, sugar and water flow are shut off by the indicator-controller.

Baldwin SR-4 systems can be developed for any application involving load, pressure, tension, torque or thrust. Custom-built systems range from simple weighing and measuring devices to complete feedback control. "Packaged" systems and component transducers are also available. For illustrated bulletins, write us at 806 Massachusetts Avenue, Cambridge, Massachusetts.

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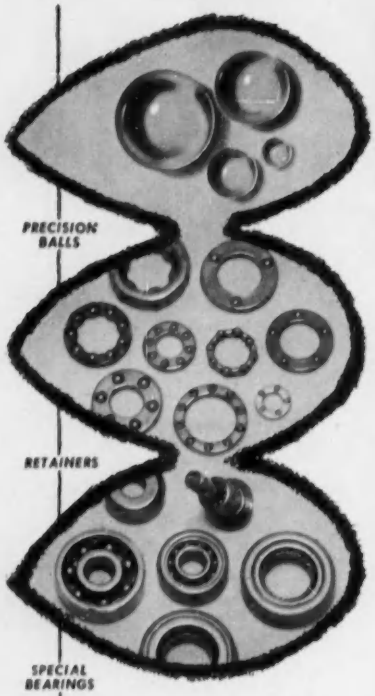

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WHAT'S NEW

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Important Moves by Key People

▶ The well-known cigarette manufacturer that incorporated it into its tagline literally put Industrial Nucleonics' AccuRay process control system on the lips of millions of Americans. When that happened, AccuRay became almost as familiar to smokers as the man behind it is to engineers. The man is **William E. Chope,** 32-year-old president of Industrial Nucleonics Corp. In 1952 Chope was named "Man of the Year" by the Columbus, Ohio, Junior Chamber of Commerce. Soon afterward the U.S. Junior Chamber presented him with its Distinguished Service Award. He's also been singled out to head the nonprofit Board of World Neighbors, Inc., organized four years ago to plant U.S. knowhow in the world's underdeveloped regions. Now Chope has been honored again: this time by Eta Kappa Nu fraternity, which dubbed him "Outstanding Young Electrical Engineer of 1955." The citation came at the Mid-Winter meeting of AIEE.

▶ Askania Regulator Co. got a chief engineer when it acquired Heinz Engineering Co. The new chief: **W. B. Heinz,** owner of Heinz and a specialist in comprehensive distillation, instrumentation, and automatic process controls.

▶ **James M. Klaasse** has been taken on by American Instrument Co. as chief engineer. An expert in seismology, physics, and electronic science, Klaasse has held posts relating to these fields with Beers & Heroy, the U.S. Naval Ordnance Laboratory, and the Office of Atomic Energy. Before joining American Instrument, he was chief engineer for W. & L. E. Gurley of Troy, N. Y.

▶ Servomechanisms, Inc., has raised **Ira L. Kasindorf,** formerly staff engineer in the Eastern Div., to chief development engineer of the Eastern Components Div.

▶ As director of engineering development, **Richard O. Endres** will supervise Rese Engineering's line of digital computer and magnetic memory core test equipment. He comes to the company from RCA's Engineering Products Div.

▶ **Dr. Louis G. Dunn** will continue to direct Ramo-Wooldridge's missile research activities in the upgraded capacity of vice-president. Before joining Ramo-Wooldridge in 1954, he headed Cal Tech's Jet Propulsion Laboratory, which developed the Corporal guided missile under his supervision. The success of the missile brought him the Army's Certificate of Appre-

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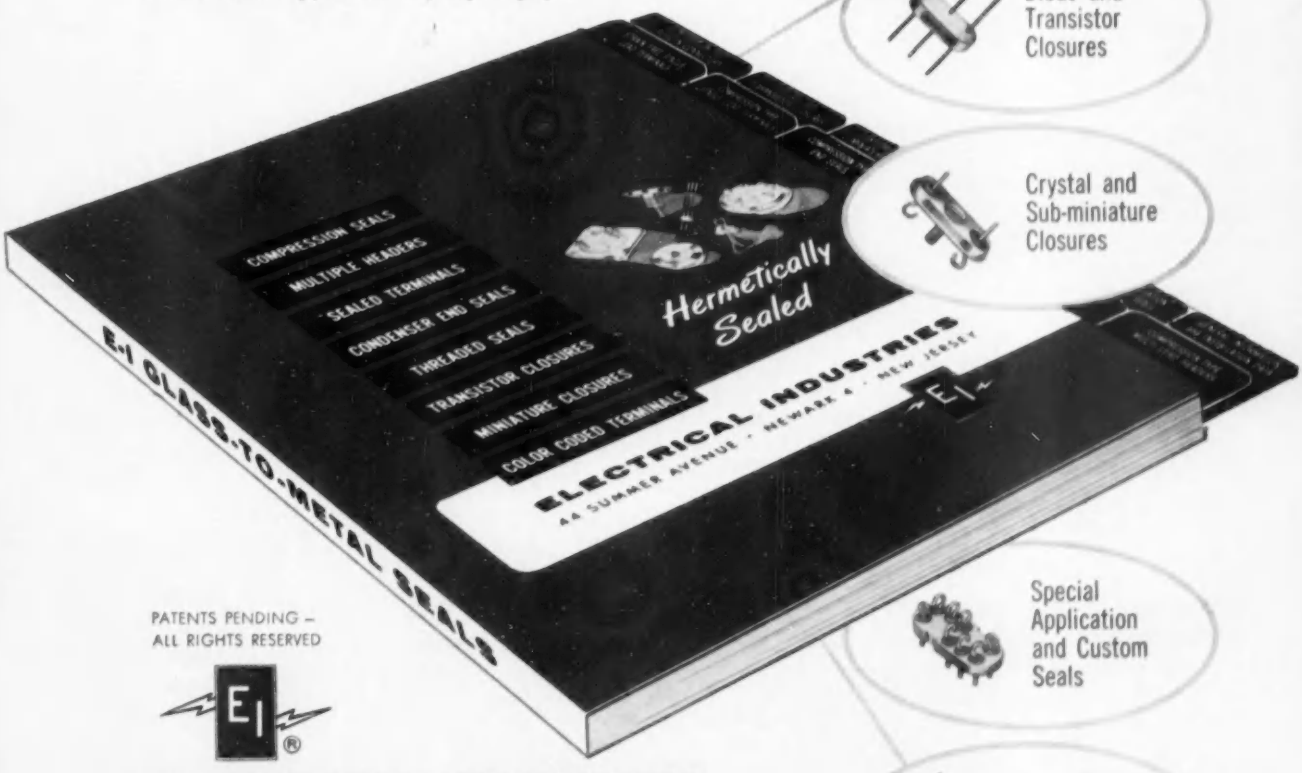

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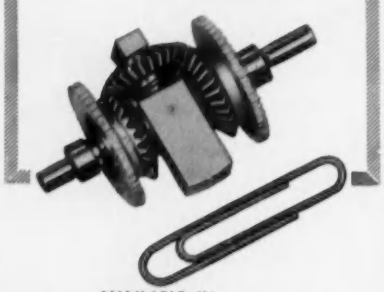

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Ford Instrument's standard components

WHAT'S NEW

ciation. At the same time **W. Stewart Hotchkiss** joins the Computer Systems Div. as assistant director for consulting services.

▶ **Leo Rosen** is the new executive director of Anderson-Nichols' Research & Development Div. His 20 patents in electronics and electromechanics attest to his prominence in these fields during the past 17 years.

▶ An Advanced Electronic Data Laboratory has been established by Consolidated Electrodynamics Corp. in Pasadena, Calif., under **Robert L. Sink,** formerly assistant director of engineering. Sink, who joined the company in 1945 as chief electrical engineer, had been with Litton Engineering Laboratories, Hewlett-Packard Co., and General Electric. He is a past-chairman of IRE's Professional Group on Instrumentation. Other CE appointments: **Gerald P. Foster,** formerly with the U.S. Naval Ordnance Test Station, Pasadena, to chief of the Systems Div.'s services section; **Francis T. Greenup,** formerly chief design engineer, to assistant chief product engineer; **Richard B. Mulock,** to assistant to the CPE, and **Charles E. Johannsen,** formerly customer-training engineer, to supervisor of the Analytical Service Laboratory.

▶ **Dr. Norman F. Parker,** who has been assistant chief engineer of the guidance section of North American Aviation's Autonetics Div., now is assistant chief of the whole division. He was with the University of California's Radiation Laboratory before joining North American in 1948. **David G. Soergel,** most recently manager of the Electromechanical Products Dept., shifts his duties to Autonetics' new Applications Dept., where he will be concerned with customer relations, market analysis, and promotion.

▶ As project engineer for WacLine, Inc., **Dr. Eugene B. Johnston** will oversee research and development of instruments and equipment for medical research. He will be assigned work in connection with WacLine's contract with the Aero-Medical Laboratory, Wright Development Center, for maintenance and instrumentation of the human centrifuge facility at Wright-Patterson AFB, Dayton.

▶ **Robert A. Gardiner** will assist Chief Engineer **Carl F. Schunemann** of Thompson Products' Electronics Div. as automatic controls consultant, a newly created post. The division's area embraces aircraft and missile controls, subsystems, and components. Gardiner formerly was with NACA's Langley Aeronautical Laboratory and Airborne Instrument Laboratories.

▶ **Edwin A. Houser** goes from Phillips Petroleum Co. to the application engineering staff of Beckman Instrument's Beckman Div.

Leo Rosen

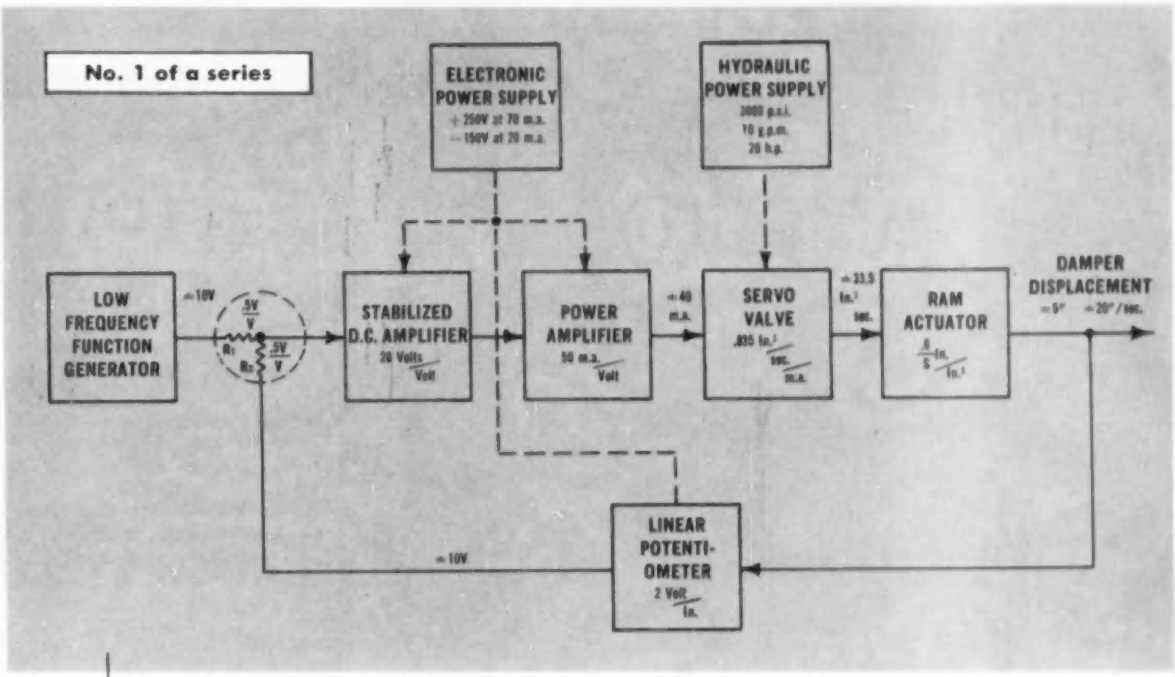
R. L. Sink

N. F. Parker

E. B. Johnston

R. A. Gardiner

E. A. Houser



How an Electro-Hydraulic Servo System solves a difficult testing control problem

PROBLEM:

A 10 inch stroke hydraulic damper with a constant of 150 pounds/inch/second required testing under various sinusoidal and constant velocity conditions up to 20 inches/second. Damper force and velocity were to be measured separately by a strain gauge and velocity transducer respectively, and displayed graphically as force vs. velocity on an oscilloscope.

SOLUTION:

A hydraulic servomechanism was used with a hydraulic system supply pressure of 3000 p.s.i. A 10 inch stroke ram of approximately 1.78 square inches area produced the required maximum force at a pressure drop under 2000 p.s.i. A servo valve was selected to produce a maximum flow rate of 35.6 cubic inches/second at a pressure drop of 1000 p.s.i.

Position feedback was accomplished by a conductive plastic, high resolution linear potentiometer mounted concentrically within the ram shaft, and the electronic input was a low frequency sine or saw-tooth wave generator.

The loop gain, which was limited primarily by the frequency response of the servo valve and the ram with load, was set at 600 /second. This determined the velocity error, which was approximately 1/600 inches/inch/second.

COMPONENTS:

Pegasus Model 140-B Electro-Hydraulic Servo Valve • Pegasus Model 230-2-10 Instrumented Ram Actuator • Pegasus Model 401-A Electronic Power Supply • Pegasus Model 402 Power Amplifier • Pegasus Model Stabilized D. C. Amplifier • Low Frequency Function Generator.

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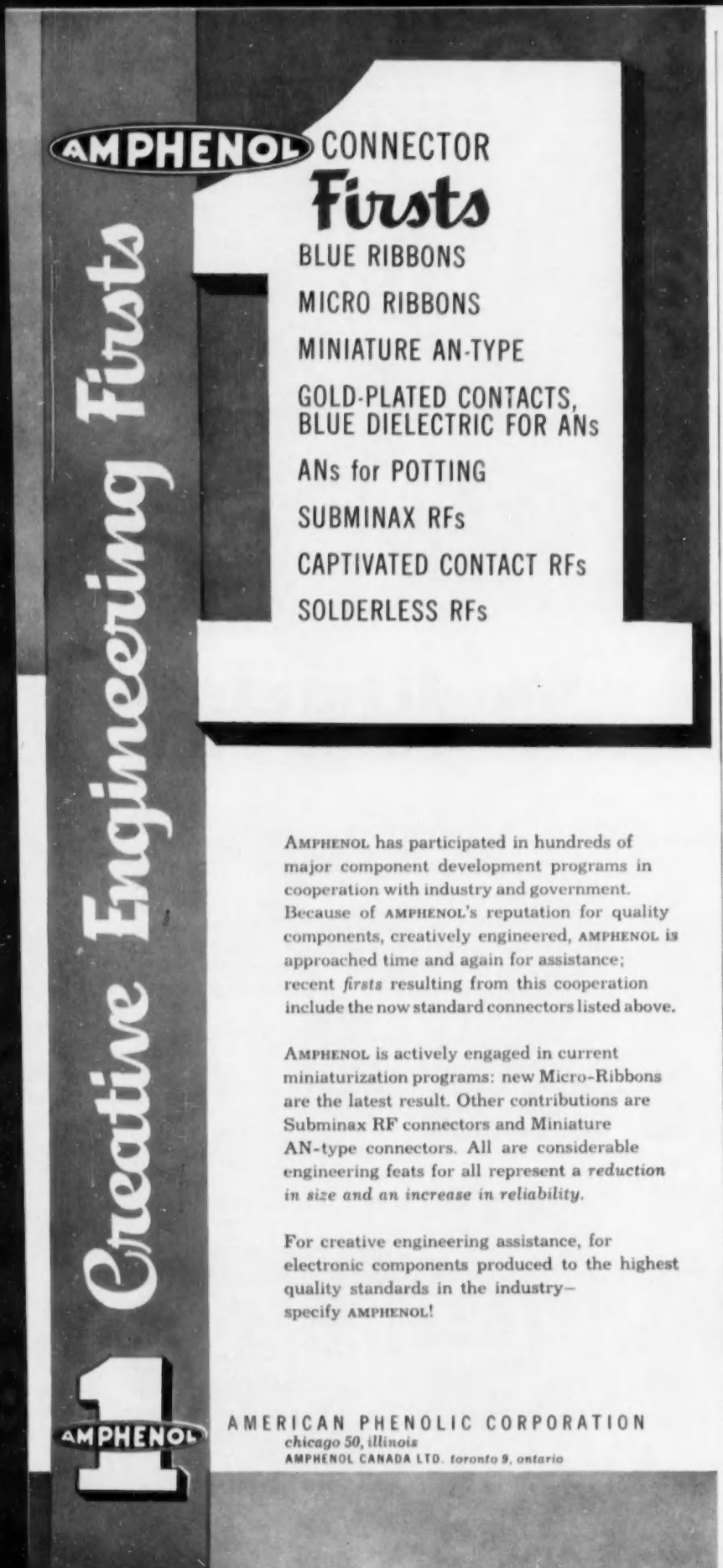


WHAT'S NEW

▶ Among the new presidents of automatic controls manufacturers are: **William M. Pease,** Feedback Controls, Inc.; **Robert W. Brooks,** Computer Control Co., and **A. P. Henry,** Control Specialists, Inc. Pease has been vice-president and general manager of Feedback Controls. Other new officers of Computer Control Co. are **Franklin R. Dean,** East Coast vice-president and chief engineer; **Kenneth M. Rehler,** West Coast vice-president, and **Robert L. Massard,** treasurer. Also elected by Control Specialists are **D. T. McRuer,** chairman; **I. L. Ashkenas,** vice-president and chief engineer; **E. T. Sprague,** secretary and business manager, and **G. E. Click,** treasurer.

▶ **Jack C. Boonshaft** and **David P. Goodwin** join CDC Control Services, Inc., as consulting mechanical development engineer and electronic development engineer, respectively. Boonshaft was with Fischer & Porter Co. as vice-president for engineering, Goodwin with Gemac, Inc., as chief engineer. Other CDC appointments: **Caldwell Jones,** automation consultant, to contract engineer; **Alfred Krieg,** instrumentation specialist, to procurement engineer, and **J. Lawrence Tecosky,** CDC secretary, to vice-president and contract manager.

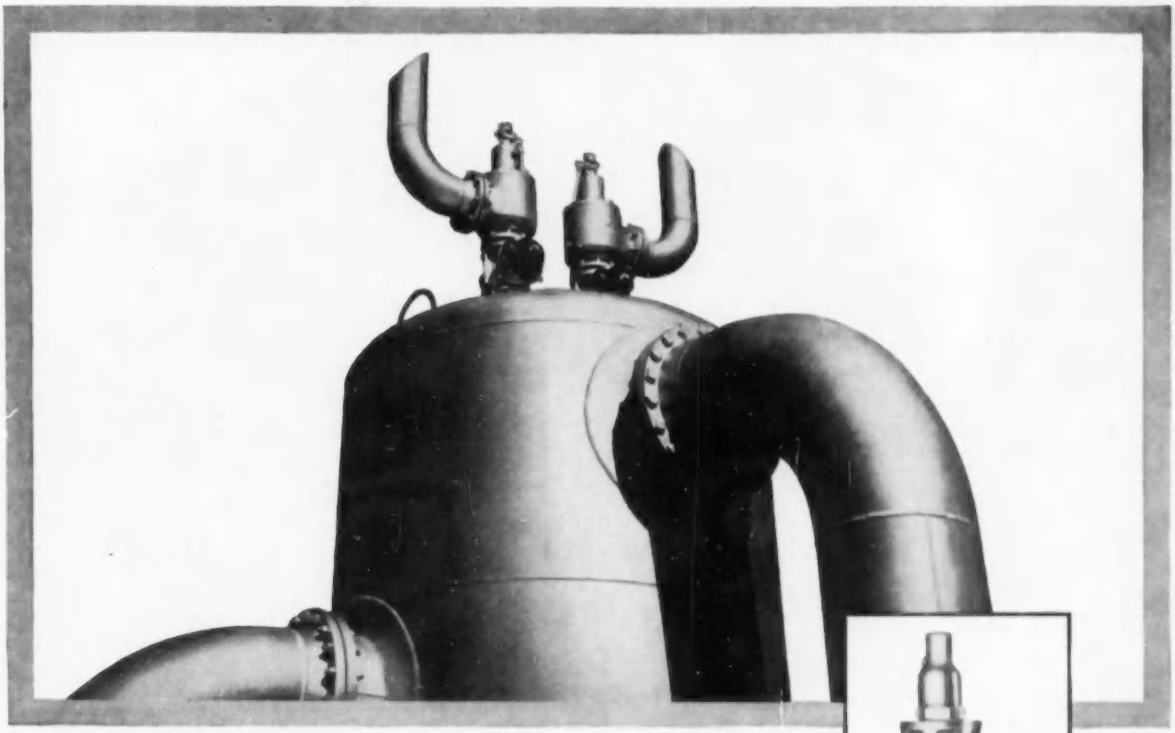
▶ Appointed by Weston Electrical Instrument Corp. are: **Samuel J. Childs** to vice-president and general manager; **Russel A. Schlegel** to manager of industrial product sales, and **John D. MacNamara** to field sales manager.

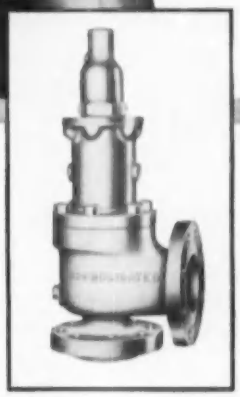
▶ Robertshaw-Fulton Controls Co. has named **Wilbur Jackson** and **Robert L. Wehrli** general managers of the Grayson Controls Div. and the Aeronautical Div., respectively. Jackson, an R-F vice-president, has been works manager of his division, while Wehrli has been Aeronautical's director of research and development.

▶ **Dr. Wolfgang Harries,** German physicist and radar expert, has joined the staff of Air Associates' Research & Development Div. Harries, who came to the U.S. in 1951, has been chief engineer for Matawan Electronics Co.

▶ Induction Motors Corp. has placed **Arthur H. Mankin** in charge of studies into dynamotors, dc motors, generators, and inverters. Mankin's new Dynamotor Dept. will be provided with instrumentation for full-scale tests under extreme temperature, humidity, and altitude.

▶ **Dr. Thomas S. Keenan** has been named administrator of the University of Rochester's new computing center, which recently got under way in





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Consolidated Safety Relief Valves satisfy *every* requirement of the most advanced processing facilities. Valve action is *consistently* positive. You get peak performance even where discharge lines are long or there is low "superimposed" back pressure in the relieving system!

The Standard type can be converted to Bellows type *in the field*. Center-to-face dimensions of inlet and outlet are such that you can interchange these valves with the safety relief valves of other manufacturers. Real flexibility of application that cuts inventory costs! Optically-ground flat seating surface and fewer functional parts than comparable valves contribute greatly to easier, more economical maintenance.

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WHAT'S NEW

earnest with the acquisition of its first computer, a Burroughs E 101. Keenan, formerly a physics instructor at Purdue, will organize the center's program and supervise installation of equipment. On tap: an IBM 650, expected next summer.

▶ Clary Corp. has appointed the following in its Electronic Computer Div.: **John Donan** to supervisor and **Chris A. Christoff** and **Ralph Powell** to engineers in charge of mechanical and electronic development, respectively. Donan and Powell joined the company in 1955, Christoff in 1941.

▶ **Ned Darling**, formerly with Hollywood Mfg. Co. and AiResearch Mfg. Co., has joined Microloc Corp. of Los Angeles as staff assistant to the general manager.

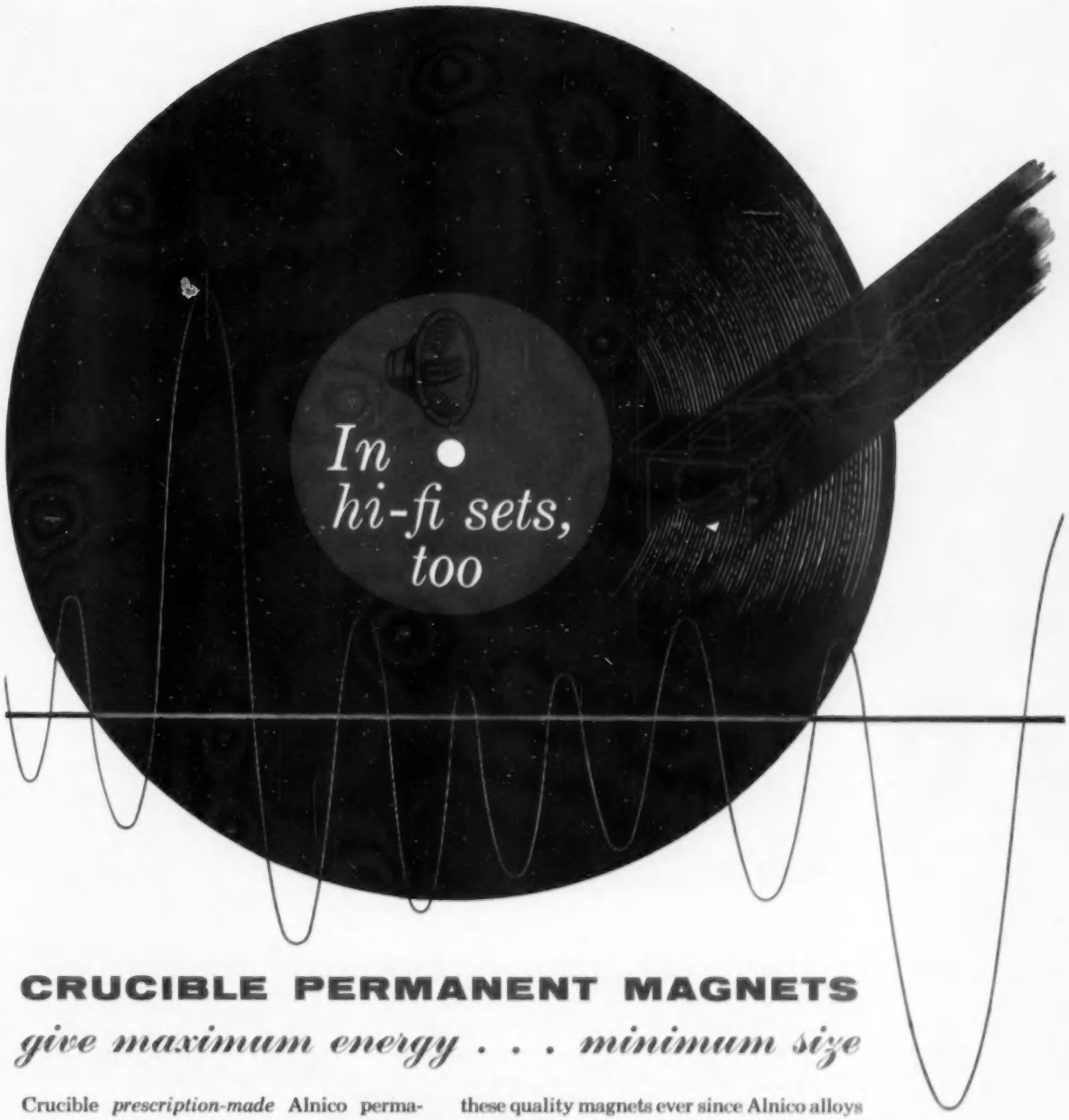
Other "Loop" News:

▶ **Sperry Rand Corp.**, which was born six months ago out of the consolidation of the **Sperry Corp.** and **Remington Rand, Inc.**, has reported some handsome figures for its first half-year. Among them: net income of $23,585,563, which was equal to 92 cents on each of its 25,464,829 common shares outstanding; and shipments of $353,943,880. Jubilant directors declared a 20-cent quarterly dividend on the common stock and a $1.12½ dividend on the preferred.

▶ Unlike Sperry Rand, **Minneapolis-Honeywell Regulator Co.** has been around for quite a spell, and its year-end figures show it. Honeywell, which makes practically nothing but automatic controls, reports its greatest year in its history. Consolidation of its European subsidiaries can be credited for some of the luster of the following figures: net income, $19,275,000, up from $15,345,203; sales, $244.5 million, up from $229,401,837. The higher sales figure was reflected in a 16-cent increase for each Honeywell share.

▶ **Fischer & Porter Co.** sent a trailer-full of process instruments on a demonstration tour of Mexico in February. The trailer visited universities, oil refineries, paper mills, and chemical, water, sewage, gas, power, and food processing plants.

▶ Some recent acquisitions: **Controls Div.** of **Brinkman Mfg. Co.** by **G. M. Giannini & Co.**; **Whittaker Gyro, Inc.**, by **Telecomputing Corp.**; **Burlington Instrument Co.** by **Texas Instruments, Inc.**, and **Linear Equipment Laboratories, Inc.**, by **Thomas A. Edison, Inc.**



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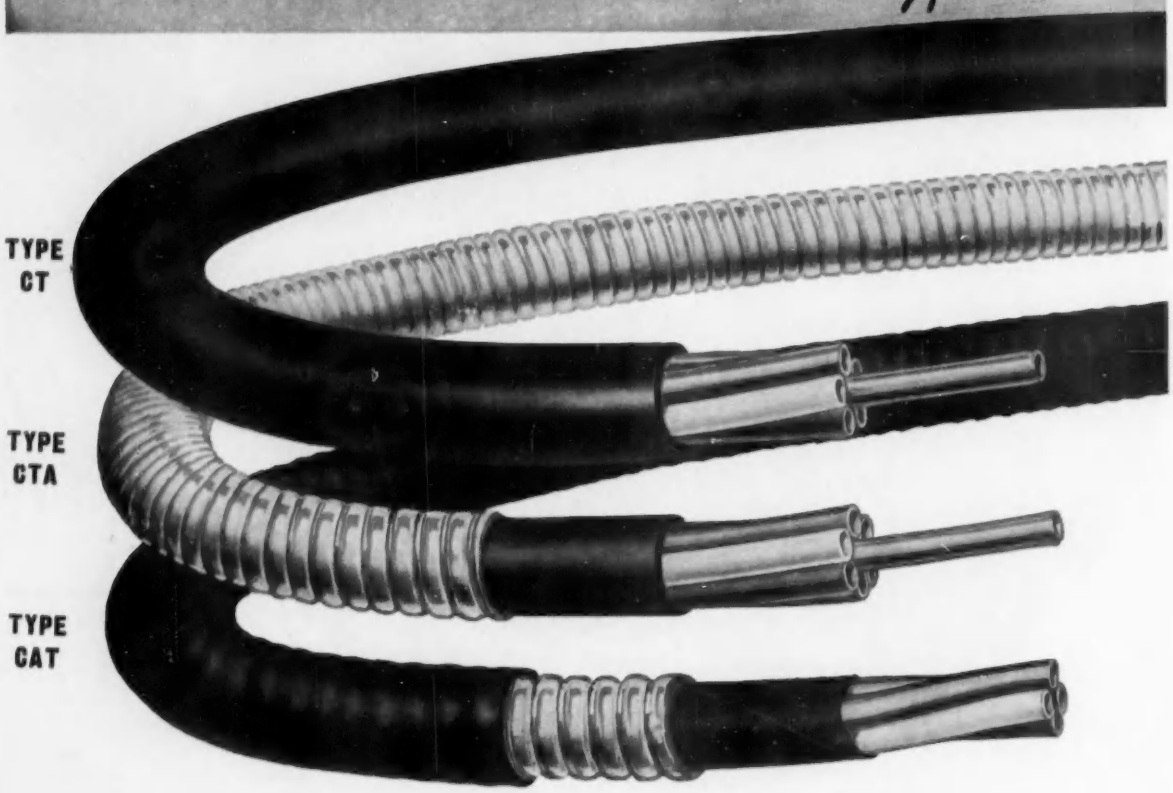
In 3 Corrosion Resistant Types



For Pneumatic and Hydraulic Instrument Controls

TYPE CT—In damp or corrosive locations where a moderate degree of mechanical protection to the tube is required, as in troughs or attached to building surfaces or supporting means, the construction shown in top view is recommended. It employs a tough corrosion-resistant thermoplastic sheath, resistant to water, acids, alkalies, oils, most chemicals, and is flame-retardant.

TYPE CTA—Where maximum mechanical protection is desired during or after installation, such as direct burial in concrete and pulling into conduit, an interlocked galvanized steel armor over the thermoplastic sheath, as shown in middle construction above, is recommended.

TYPE CAT—For maximum protection against corrosion and mechanical injury to the tubing, the thermoplastic sheath is applied over the flexible steel armor as shown in the bottom construction illustrated above.

These forms also provide the other advantages possessed by CRESCENT ARMORED MULTITUBE which include permanence, lower over-all cost and ease of installation.

CRESCENT ARMORED MULTITUBE consists of long length tubes **TWISTED TOGETHER** to permit bending without distortion. In each layer one tube is a bright blue color, affording a fast means of identification from both ends.

Available in long runs up to 1000 feet and up to 19 tubes of copper, aluminum or polyethylene tubing in size $\frac{1}{4}$" O.D. This product is licensed under U.S. Patent 2,578,280.

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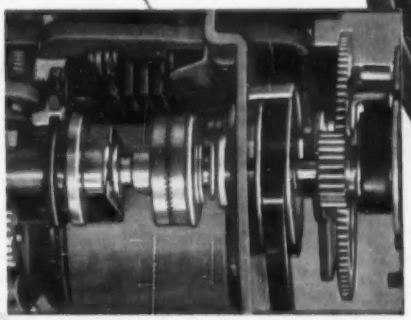

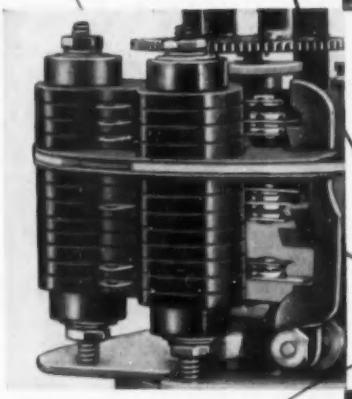

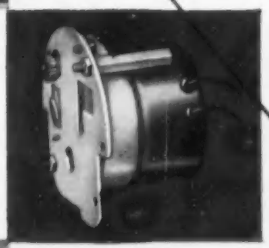

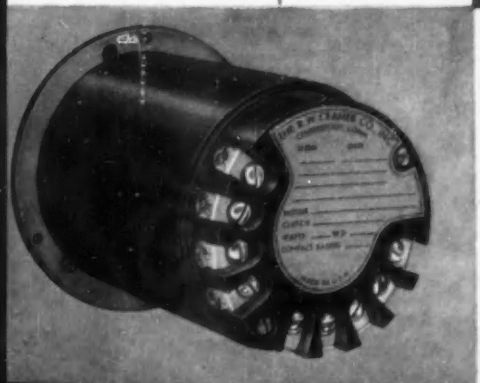

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NEW Contacts, rated 15 amps., give positive quick-make, quick-break operation. Contacts are of silver cadmium oxide with ability to handle high inrush currents.

NEW Flexibility in wiring. Nine-position terminal block offers side or rear connection, presents a variety of wiring possibilities.

NEW Reset Shock Spring Design laboratory tested for more than a million operations.

NEW Friction Setting Mechanism allows adjustment even while timer is operating.

NEW—Ratchet Clutch operated by powerful relay, provides instant action, no slip.

NEW O-Ring Retainer permits quick removal of bakelite housing, exposing entire timer mechanism.

Timer driven by high torque (30 in. oz. at 1 r.p.m.) Cramer Type 112 Synchronous Motor.

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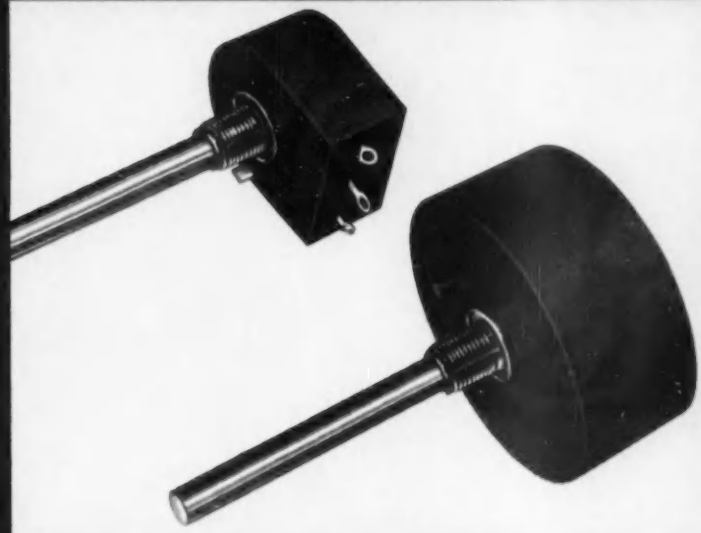

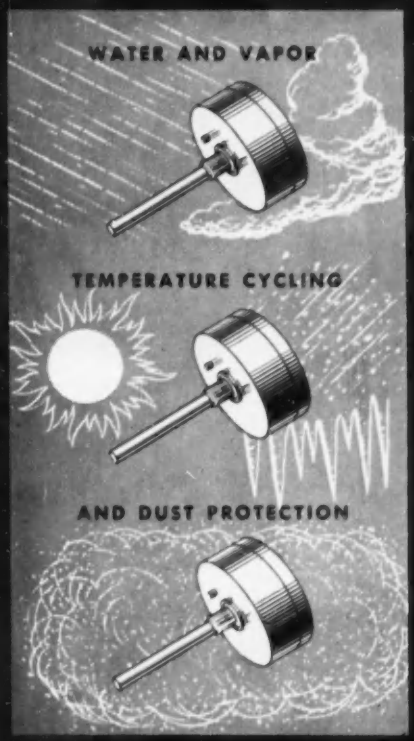

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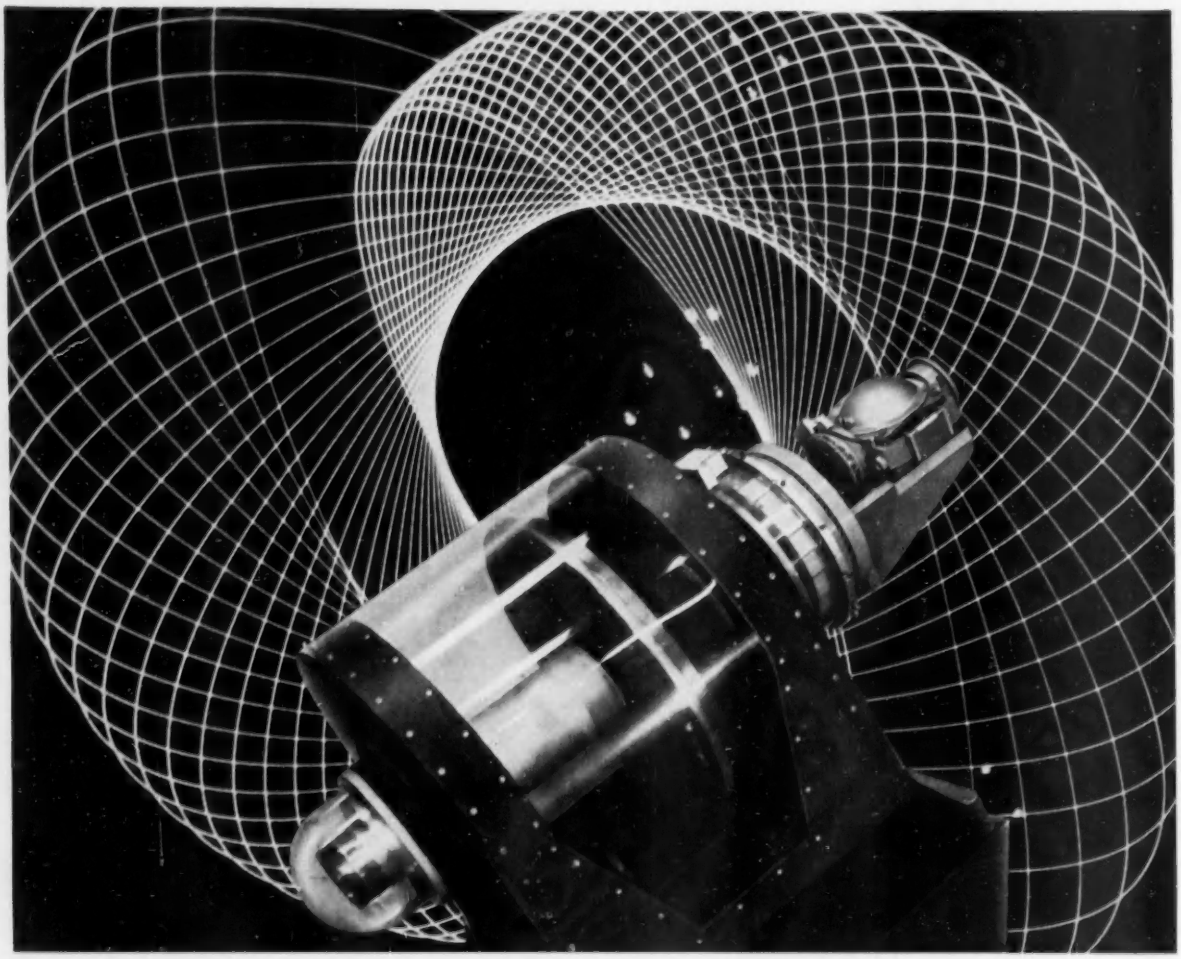


$$\bar{r}(t) = \int_0^t (t - \tau) \left[\frac{d^2\bar{r}}{d\tau^2} - \bar{\omega} \times (\bar{\omega} \times \bar{r}) - \frac{d_r\bar{\omega}}{d\tau} \times \bar{r} - 2\bar{\omega} \times \frac{d_r\bar{r}}{d\tau} \right] d\tau$$

$$\bar{L} = \frac{d_r}{dt} (\bar{\bar{I}} \cdot \bar{\omega}) + \bar{\omega} \times (\bar{\bar{I}} \cdot \bar{\omega})$$

People who write ads are not supposed to know a great deal about equations like these, and frankly we don't. But we have the feeling *you* recognize them as basic to the development of inertial guidance systems. More specifically, we understand they are the vector equations which, in effect, must be mechanized through the use of either digital or analog techniques.

AUTONETICS, a division of North American Aviation, Inc., has been implementing these and other mathematical truths for more than 10 years. This work is in the hands and minds of the engineers and scientists in our 2,200-man engineering department. They have achieved outstanding results in producing complete guidance systems for airplanes and missiles. Also, important precision elements of such systems have been developed through a complete understanding of these and other equations.

AUTONETICS has complete facilities for the research, development, design flight test and manufacture of inertial guidance systems . . . as well as autopilots, armament controls, computers and special products.

If your professional interest is stimulated by this advertisement, and you would like to know more about AUTONETICS — please write: AUTONETICS, Dept. CON-N, 12214 Lakewood Blvd., Downey, California.

Autonetics

A DIVISION OF NORTH AMERICAN AVIATION, INC.

AUTOMATIC CONTROLS MAN HAS NEVER BUILT BEFORE

How to Keep Blood From Freezing

No. 1 of a series — *Showing the broad application range of Fenwal Controls*

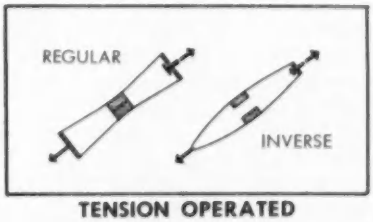
The problem was one of providing warning if blood under refrigeration was subjected to temperatures below 32°F or above 48°F. Here's how Fenwal Thermoswitch units solved it.

Fenwal Thermoswitch units were connected in parallel series. The regular type #17000, which opens on temperature rise, closes when the temperature falls to its setting of 32°F. The inverse type Fenwal Thermoswitch unit, which closes on temperature rise, closes when the temperature rises to its setting of 48°F. Between 32°F and 48°F, both Thermoswitch units are open so that no alarm is given.

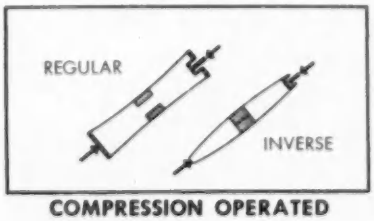
How Fenwal Thermoswitch® Units Operate

In Thermoswitch thermostats the activating *control* element is the metal shell which encases the contact elements. Changes in temperature cause the shell to expand or contract instantaneously. This exerts either tension or compression on the struts, causing the contacts to make or break a circuit. Control in the Fenwal Thermoswitch units is calibrated at a given shell temperature by turning the adjusting screw until contacts operate.

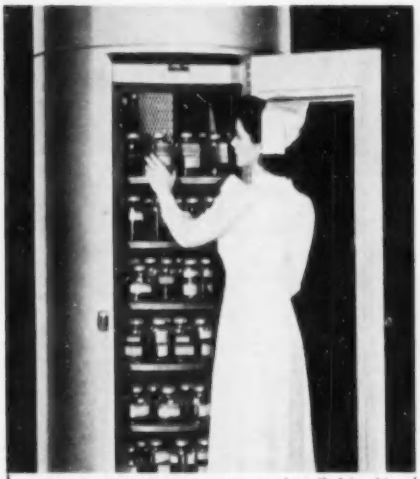
Fenwal Thermoswitch Controls are constructed as either tension or compression operated with regular or inverse contact arrangements.



TENSION OPERATED

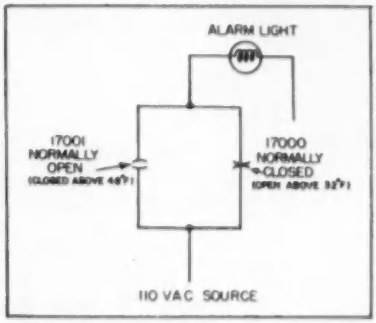


COMPRESSION OPERATED



FENWAL THERMOSWITCH UNITS are installed in this blood bank to prevent blood from freezing. Compact Fenwal units are easily adjustable, highly resistant to shock and vibration and are totally enclosed against dust and dirt.

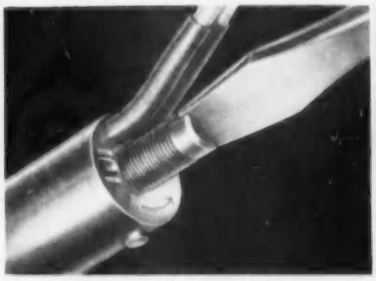
Tension operated units may be subjected to momentary temperature exposure of 100°F above their set point. They also may be subjected to any temperature below their set



point without danger. Tension operated Fenwal Thermoswitch units may be set below 0°F but compression operated units are recommended if rapid temperature changes in excess of 100°F or extreme temperature overshoots are to be encountered.

The Fenwal Thermoswitch Control is constructed with two silver contacts mounted on, but electrically insulated from, curved nickel-iron struts of low expansion coefficient. This element assembly is then mounted under tension or compression in a seamless drawn brass or stainless steel tube. The amount of tension or compression is variable, depending on the position of the adjusting sleeve and the temperature of the shell.

Fenwal compression operated units may be exposed to a temperature of −100°F indefinitely, and to temperatures 400°F above their set temperatures for short periods of time.



Proved Applications

Fenwal Sales Representatives and Engineers have saved time, trouble and money in all types of plants and laboratories by solving thousands of temperature control and detection problems. Fenwal Thermoswitch units are controlling processes that involve liquids, gases and solids.

Put Fenwal's vast reservoir of technical know-how to work for you. Chances are your problem has already been met and mastered by Fenwal engineers.

Write for new Catalog No. 500 for details and complete product listings on Fenwal Thermoswitch Thermal Controls, including units discussed above, Midget and Miniature versions of these, Snap-Action Controls, and Indicator Controllers.

FENWAL INCORPORATED
594 Pleasant Street
Ashland, Mass.

Please send me your Catalog No. 500. Our specific problem is:.....

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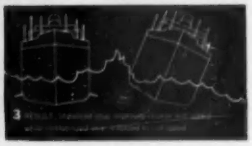
Name.....*Title*.....

Address.....

City.....*Zone*...*State*.....

Fenwal CONTROLS TEMPERATURES . . . *PRECISELY*

PACE and Progress



FOLDING FINS TO TAME ROUGH SEAS

Stabilizer Cuts Ship's Roll Up to 90%

THE STORY BEHIND THE STORY

"Now I'd like to take a cruise more than ever!"

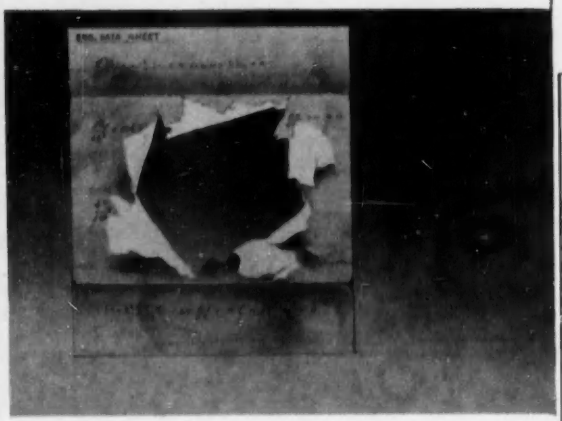
• That, probably, was the reaction of most people when radio, television and the nation's press announced recently an effective way of taming rough seas. But to shipowners and shipping men the announcement meant more than passenger comfort alone. It offered substantial savings – by reducing damage to ships and cargoes, by improving interest and speed in heavy weather thus saving fuel and time between ports.

• To understand how the Sperry Gyrofin® Ship Stabilizer is able to tame mountainous seas and eliminate up to 90% of the hermes roll, take another look at the illustrations above. The hydrofoil-type fins are constantly pre-tensed to exert anti-roll forces of precision magnitude and timing. Controlled by sensing devices that anticipate each roll of the ship, one fin literally "pushes down" while the other "lifts up" – and even the biggest wave is subdued!

• In bringing this development to the maritime trade, Sperry engaged the hydrodynamic experience and shipbuilding facilities of the Newport News Shipbuilding and Dry Dock Company. And many highly specialized Sperry skills were combined to make this development possible. The sensitive controls, for example, result from Sperry's vast experience in designing gyroscopic and electronic systems – the enormous power from Sperry's knowledge of hydraulic and servo systems.

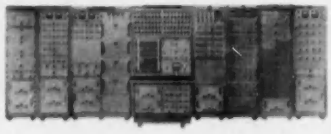
• These combined skills have also been responsible for many of our nation's most effective weapons of defense and for the most advanced instrumentation for ships of the sky and of the sea. *

SPERRY GYROSCOPE COMPANY
Great Neck, New York
DIVISION OF SPERRY RAND CORPORATION



Break Through The PROBLEM Barrier

More and more engineers are turning first to Electronic Associates Analog Computing Groups to conquer the problem barrier. For in these Groups they find an unparalleled accuracy, reliability and flexibility that has been proved by thousands of operational hours. These groups feature a building block method that simplifies the economical expansion of the system by the addition of standard component groups. A complete Group and staff is available for your experimentation on a rental basis at Electronic Associates Computation Center just outside of Princeton, New Jersey. We will also gladly furnish details on our new line of high-speed sounds, problem checks, high accuracy Electronic Multipliers, Function Generators and precision output equipment. Write Dept. 1A-5



ELECTRONIC ASSOCIATES — EAI SETS THE PACE (PRECISION ANALOG COMPUTING EQUIPMENT) — LONG BRANCH, NEW JERSEY

In the development of the Gyrofin* Ship Stabilizer, Sperry Gyroscope Company's Marine Division employed EAI's Precision Analog Computing Equipment—Equipment renowned for its unparalleled accuracy, reliability, and flexibility. One more example of two foremost companies working together to break the problem barrier through progressive engineering. Write Dpt. CE-4, for details on Pace Equipment and the rental of time and equipment at the EAI Computation Center in Princeton, New Jersey.

*Sperry T. M.

ELECTRONIC ASSOCIATES Incorporated — EAI SETS THE PACE (PRECISION ANALOG COMPUTING EQUIPMENT) — LONG BRANCH, NEW JERSEY

A Control Reporter Tours the Netherlands

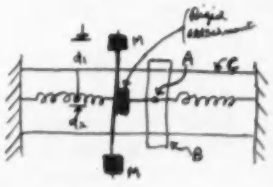
(Corresponding overseas with CONTROL ENGINEERING is Philadelphia engineer Melvin Fusfeld. In his first letter Mel tells how he found control in Holland. Below are some lively fragments.)

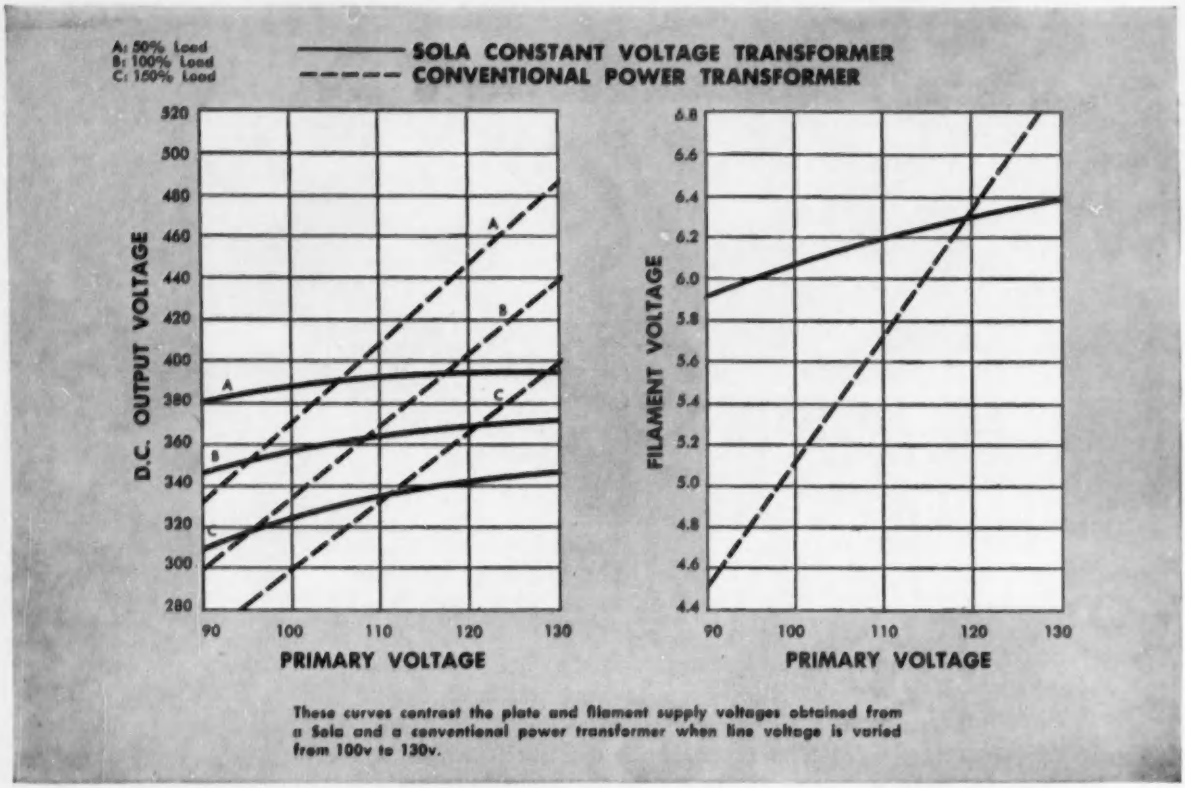
Europe picks up the describing function

"We had a long talk with J. M. L. Janssen (CtE, November and December '55) one evening concerning the development of control theory in the Netherlands. This alert engineer is fast building a world reputation for his work at Royal Dutch Shell's Delft Laboratories. Enhanced by furiously drawn tablecloth sketches, most of our chat concerned the behavior of nonlinear systems and I noted that the describing function —a mighty powerful tool for U. S. workers—is only now coming into its own in Europe. Interestingly enough, the characterization of nonlinear systems by means of correlation techniques had been exhaustively studied and found wanting. 'Correlation is fine,' remarked Janssen, 'if you can tell whether your bump is cause or effect. But your system does not have to become very complex before you are not sure from which end you are trying to correlate.' He mentioned in passing that he had seen some Russian papers that used a sort of describing function that was more of a theoretical than a practical tool like the Johnson-Kochenburger technique . . .

"It's only a toy now, but . . . ?"

"Janssen has set up a very intriguing toy in his laboratory. The bane of every control engineer has always been the seemingly immutable decay curves displayed by his systems. Janssen's toy (see his sketch) consists of a spring-mass system riding on ways designed so that friction is proportional not to velocity, but to acceleration. The slider, B, mounted on the ways, C, is free to move with or against the springs. On the slider there are two masses, M, which are free to pivot about point A. Now if $d_1 = d_2$ we have the conventional free vibrating mass system with its usual oscillatory or asymptotic decay curve. However, if $d_1 \neq d_2$, we produce a couple that acts on the slides to increase friction on the ways—and this frictional force is, of course, proportional to the system acceleration.





These curves contrast the plate and filament supply voltages obtained from a Sola and a conventional power transformer when line voltage is varied from 100v to 130v.

Improve performance of control components with built-in regulating power transformer

You can make sure your product will always receive correct plate and filament voltages by building in a Sola Constant Voltage Power Transformer (Type CVE) in place of a conventional, non-regulating power transformer.

The Sola CVE provides ±3% regulation of plate and filament supply, with line voltage variations of 100 to 130 volts. Regulation is completely automatic, continuous and substantially instantaneous (1.5 cycles or less). Sola CVE stabilizers have no moving parts or tubes, require no manual adjustments or maintenance, and are self-protecting against short circuits.

Three stock units (all with high voltage ct, 5.0v and 6.3v regulated windings) are stocked by your electronic distributor. You can order production quantities of special units manufactured to your specification. We invite your inquiry.

TYPICAL STOCK UNIT: Sola Electronic Power Transformers are made for chassis mounting. They are furnished complete with separate capacitors and capacitor mounting brackets.

Automatic, Maintenance-Free Voltage Stabilization

SOLA *Constant Voltage* **TRANSFORMERS**

SEND FOR FOLDER:
Please write for folder which gives complete data.
Ask for CIRCULAR 26D-CVE-195

CONSTANT VOLTAGE TRANSFORMERS for Regulation of Electronic and Electrical Equipment • **LIGHTING TRANSFORMERS** for All Types of Fluorescent and Mercury Vapor Lamps. • **SOLA ELECTRIC CO.**, 4633 West 16th Street, Chicago 50, Illinois, Bishop 2-1414 • NEW YORK 35: 103 E. 125th St., TRafalgar 6-6464 • PHILADELPHIA: Commercial Trust Bldg., Rittenhouse 6-4988 • BOSTON: 272 Centre Street, Newton 58, Mass., Bigelow 4-3354 • CLEVELAND 15: 1836 Euclid Ave., PRospect 1-6400 • KANSAS CITY 2, MO.: 406 W. 34th St., Jefferson 4382 • LOS ANGELES 23: 3138 E. Olympic Blvd., ANgelus 9-9431 • TORONTO 17, ONTARIO: 102 Laird Drive, Mayfair 4554 • Representatives in Other Principal Cities

Now the thought-provoking feature of this system is that its decay curve looks like a portion of a sine curve! And note, too, that since friction is proportional to acceleration we can exercise one of the venerable laws of physics and treat the friction like an artificial mass ($F = MA$). It's only a toy now, but—? . . .

"Again and again in conversations, European engineers sooner or later pop up with the expression, 'But of course you in the States are way ahead of us in that field.' Then looking about me I try to find just where we are ahead and more often than not end up by concluding that European technology in that particular field is right up to ours. True, there are some places where we do have a lead. But I sense a distinct and unjustified inferiority complex on the part of the European. Perhaps it's due to his being more gullible than his hardened American colleague when it comes to America's prodigious commercial-technical ballyhoo. Frankly, the European instrument engineer seems to be better educated, but he has less practical experience than his American equivalent. Our engineering has always been characterized by the search for the 'golden mean' (to borrow a term from Plato). The mature, experienced American engineer seeks not the elusive perfect solution to his problem but, rather, the solution that will just fulfill the requirements of the job at hand. There seems to be more of a tendency in Europe to 'research the hell' out of a problem to find the best of all possible solutions. On the other hand, the European instrument man seems to be less apt to go into the laboratory half-cocked. Generally, lab work is not started until thorough study and statement of the problem have been made. There is far less of the 'why waste time talking, let's try and see' attitude, which sometimes results in heavy commitments of lab material and time for testing ideas that might have been desk-examined far faster, and at less expense . . .

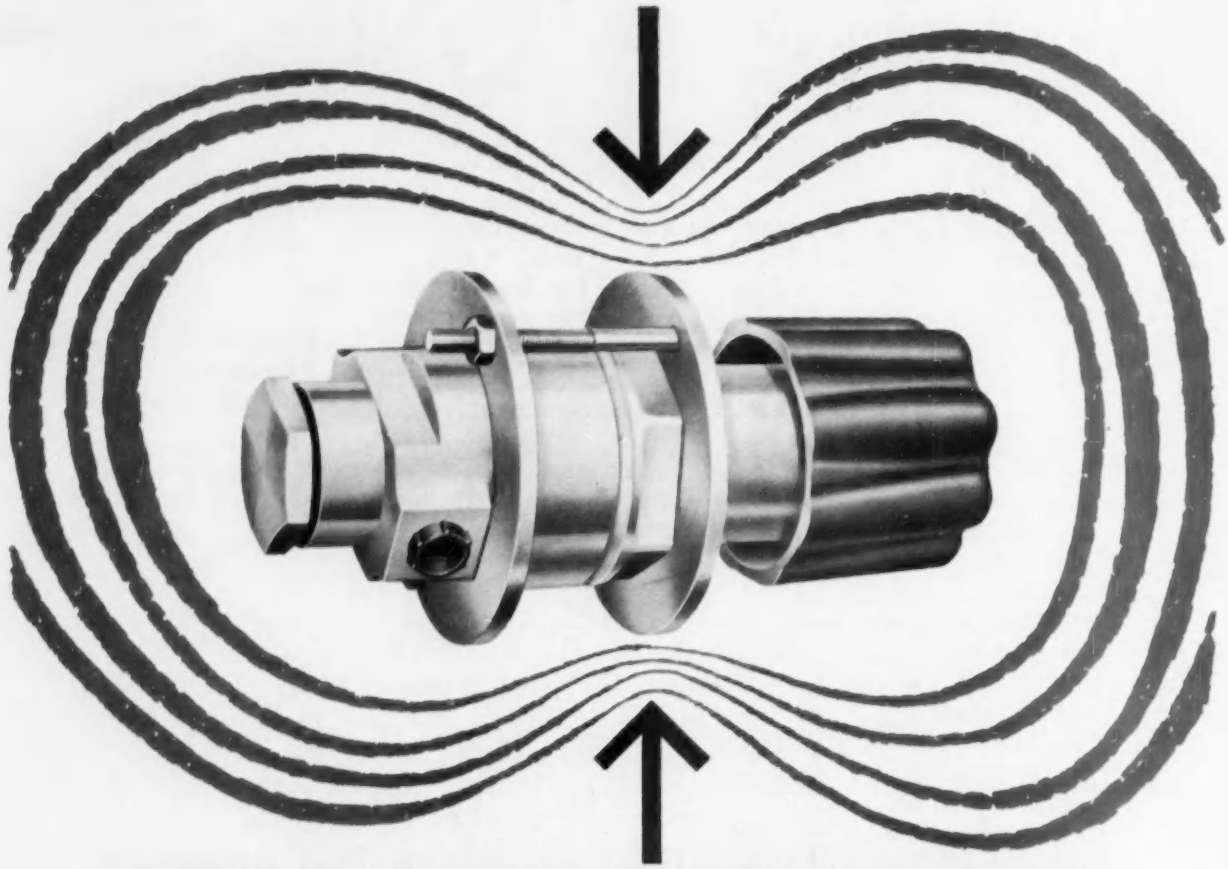
European vs. American control engineers

"The B.P.M. laboratories at Amsterdam have finished installing their large-scale Ferranti digital computer—one of the first of its size completely devoted to solving technical problems. Much of its operating time will be spent investigating control systems. When I visited, the computer was establishing stability criteria for a rather complex interacting loop system . . .

Making it easier for Dutch control manufacturers

"One of the factors that has stimulated growth in the booming Dutch instrument industry is the import tariff credit plan. Whenever a manufacturer in the Netherlands imports parts or material for products that he will subsequently export, he recovers the tariff he paid on these parts when he finally ships his finished product from Holland . . .

"Visiting with the head of the instrument department of one of Europe's largest oil companies, we got into a discussion of



A REVOLUTIONARY, NEW HIGH PRESSURE REGULATOR

Look at these outstanding new developments:

- Widest adjustment range available for manual regulation due to greater sensitivity created by a new engineering innovation!
- ¼" tube straight thread gasket seal bosses per AND10050!
- Maximum inlet pressure of 4500 psi!
- Internal relief valve and filter!
- Internal valve and filter are removable without disturbing spring and diaphragm structure!

Catalog Number	Adjustable Range Outlet Pressure psi
110100-2	5/150
110100-4	15/300
110100-6	30/750
110100-8	150/1500
110100-10	400/3000

Write today for new engineering data sheet and catalog covering our complete range of regulators.

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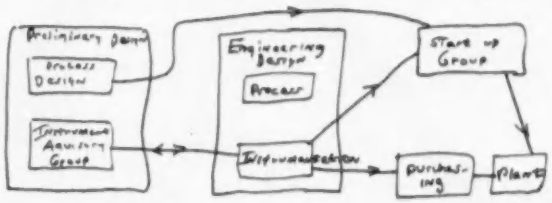
'organizing for new plant instrumentation.' The flow-sketch he drew is revealing. The people responsible for laying out the



Putting the control bite on plant designers

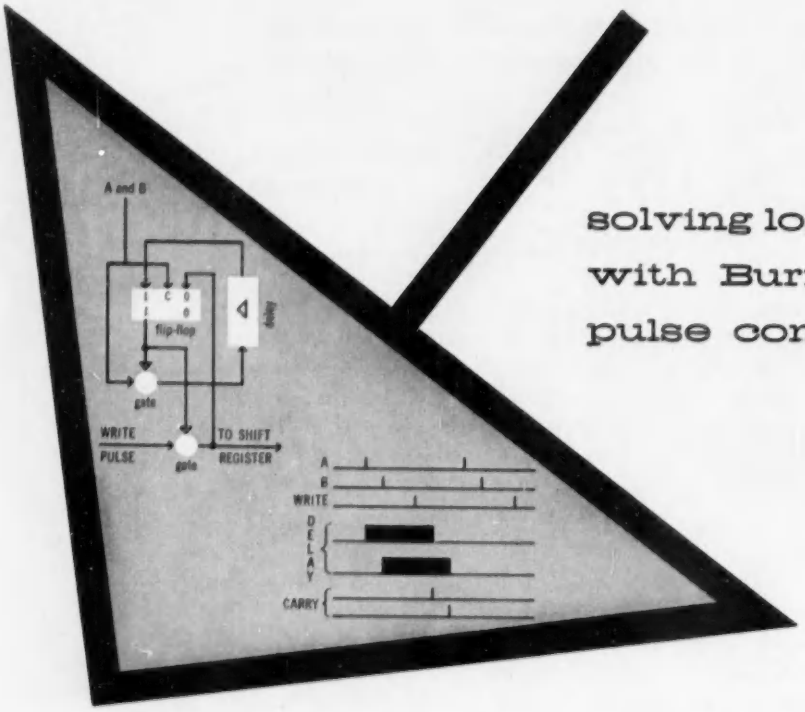
new plant work with an instrument advisory group so that the process can be 'designed for control'. The actual selection and specification, though, are done in the Engineering Design Div. The startup group is a pickup section composed of instrument engineers from the Design Div. and process engineers from the preliminary design group. An organization such as this not only insures plant design for control, but sees to it that the preliminary design people realize that whatever they concoct has to run . . .

"By-pass valves or no by-pass valves? A question that has provoked more than one hot discussion in the U.S. is a burning issue in many plants over here. Immediately after the war by-pass valves were ruthlessly removed from around instrumentation in all new plants as an economy measure. The philosophy was also fostered by cut-throat competition among engineering design firms bidding on a job. Of late, the pendulum seems to be reversing—the new plants I visited have added the by-passes. However, only yesterday I went through a spanking new power plant—attached to a paper plant and one of the largest captive units in Europe—which was just trying to go on line. Not a by-pass or even shutdown valve in the whole plant! Hence every time an adjustment was needed on a control valve or primary, the plant had to be shut down. The project engineer for the design firm was walking around with bags under his eyes as big as basketballs. But somehow or other it always turns out that the instrument supplier gets the blame . . .

Are by-pass valves necessary?

"Here is another strange method for justifying equipment purchase. Some of the petroleum companies with refineries in colonial possessions have a policy of selecting control equipment on the basis of its complexity and elaborateness—and its need for skilled operators and maintenance men. Reason: to discourage native governments from trying to take over and run the refineries . . ."

One reason for buying overly complex controls



solving logical problems with Burroughs pulse control systems

a one flip-flop serial binary adder

... conceived and proved in the same day

This new and unique serial binary adder will find many uses in digital work. But it might never have been developed without Burroughs Pulse Control Equipment to act as a catalyst for the engineer's imagination.

The engineer who developed the adder, like all others in logical design, is constantly faced with the problem of finding new components which require a certain amount of experiment and imagination. He is most efficient when using equipment that is as flexible as the problem and capable of keeping pace with his thinking. In this case, for example, his problem was reduced to: (1) setting down the idea in block diagram form, (2) interconnecting his Burroughs units accordingly, and (3) checking results.

His original idea was quickly brought to working reality, because a Burroughs System eliminates many of the usual steps in between. And while setting down the diagram for the system hook-up, he was automatically specifying not only the equipment he would ultimately need to build the unit, but also how to assemble it. Thus, he did away with breadboard hardware entirely.

You can give yourself the same creative edge by letting a Burroughs Pulse Control System give your imagination a chance to work. Just send us your pulse problem, and we'll gladly work out a Burroughs Pulse Control solution . . . at no cost. Or, write for Bulletin 236.

tools for engineers

Burroughs

BURROUGHS CORP. • ELECTRONIC INSTRUMENTS DIV.
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Control
ENGINEERING
APRIL 1956

Engineers Are Investments

Are you—the control engineer—a professional or not? Certainly you are subject to the same economic environment as nonprofessionals. You procure food, clothing, housing, transportation, and entertainment in the same market as the unskilled worker and the skilled technician. Hence, say the proponents of collective bargaining for engineers, you are not essentially different than production, craft, or clerical workers. Further, according to the American Federation of Technical Engineers (AFL-CIO) and the union-affiliated Engineers and Scientists of America, you have no better position in job bargaining within the corporate structure than the hourly paid worker. Therefore, they say, you should join forces with your ilk and negotiate binding contracts.

On the other hand, says Milton F. Lunch for the National Society of Professional Engineers, "professionalism and unionism are incompatible concepts . . . engineering is a profession". . . and the solution lies in intensified cooperation between top management and the professional engineer.

The unionist's excellent argument is built upon the engineer's drive for economic well being—today. It calls for: selection by qualification rather than wholesale hiring, regular job and salary review, and prompt settlement of grievances. But can the unions assure the engineer of a continuing increase in his basic investment—training?

We suggest that both camps consider the engineer an investment: an investment of time, training, and experience that pays off on today's "squeaky wheels". But more important: he should be thought of as a major investment in his company's long-term progress. All will agree that a good long-term investment should be increased—particularly in the fast-moving control field. This means arranging time for the engineer to keep up with his field by study and reading, and by attending the meetings of technical societies. It also means providing facilities for his research and encouraging him to publish and to teach his findings.

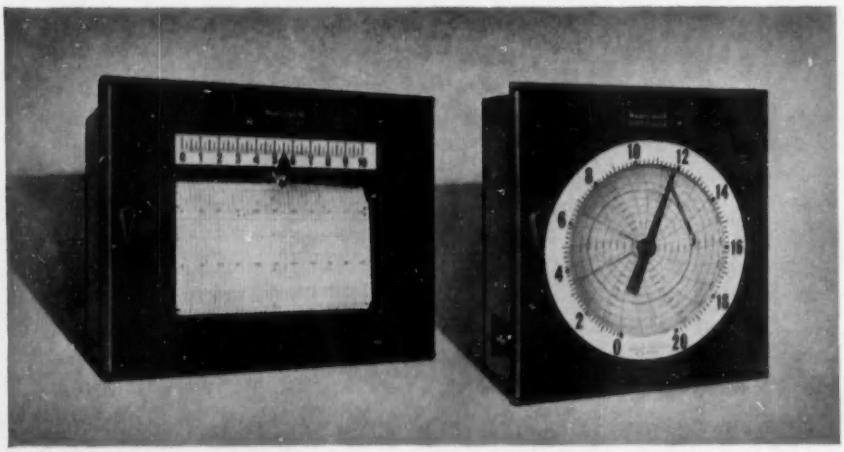
Only by being considered—and treated—as a good investment can the engineer bring maximum profit, both to his company and to himself.

THE EDITORS

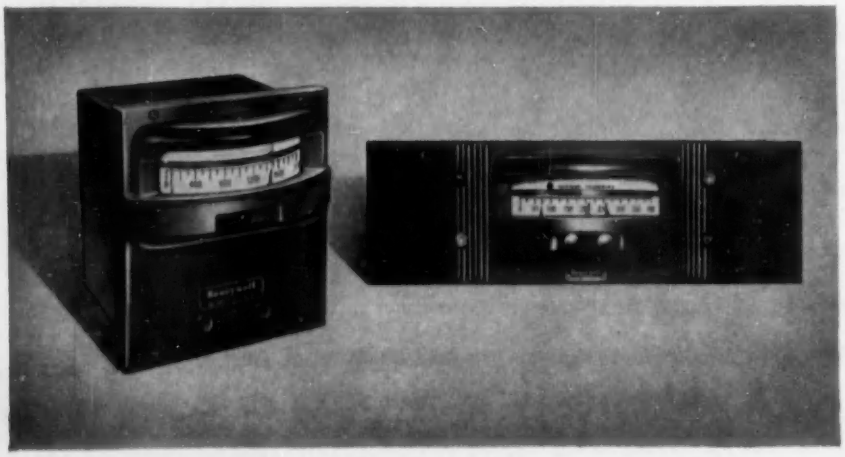
• *for accuracy, versatility, price*

The Precision Class 15 Line of *ElectroniK* instruments has calibrated accuracy within ±.25% of scale span. Models include strip and circular chart recorders, Precision Indicators, circular scale indicating controllers, Vertical Scale Precision Indicator. Electric and pneumatic control from simplest to most complex types. Multi-point monitoring or recording of 2 to 400 separate inputs.

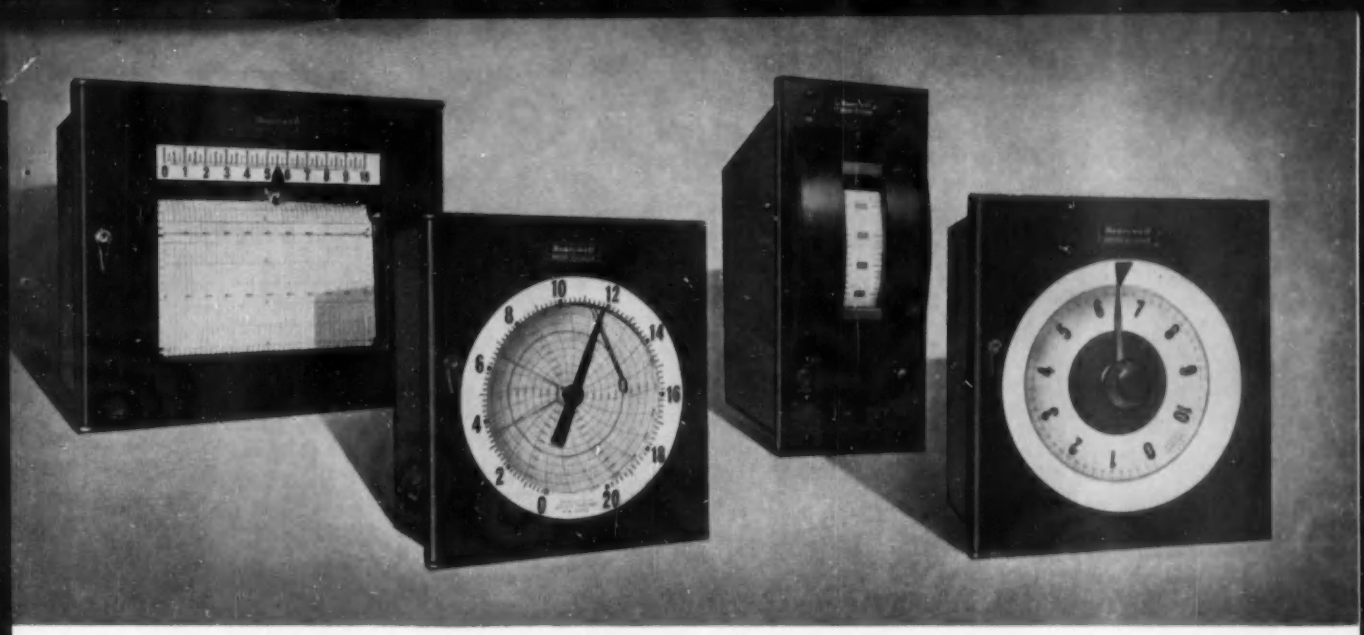
...Let your application decide



The Special Class 14 Line of *ElectroniK* instruments is calibrated to an accuracy of ±.5% of scale span . . . priced lower than the Precision line. Includes strip chart and circular chart recorders and recording controllers, also circular scale indicating controllers. Electric control of the contact, time-proportioning or position-proportioning type is available.



Millivoltmeter Instruments give dependable and accurate service, at low cost. High-resistance galvanometer circuit minimizes effects of varying length of extension wires. Plug-in unit design speeds servicing. *Pyr-O-Vane* controllers, in either horizontal or vertical case, give snap-action electronic vane control or pulse-type time-proportioning control.



which Honeywell instrument

fits your needs

GOT a temperature measurement or control job to handle? There's no need to "shop around." For from *one* source—Honeywell—you can be sure of getting exactly the right instrument to fit your needs.

This is the time-saving—and money-saving—way to choose instruments. You can choose from the most complete, most diversified line of pyrometric instruments on the market. Your selection can hit the application right on the button—giving you the performance you need at the price that fits your budget.

For the peak in precision and versatility, there's the "Precision" *ElectroniK* line. This is the pioneer "continuous balance" electronic instrument that thousands of plants and laboratories have used for many years. It's available in eleven basic models, and can provide automatic control action from the simplest to the most advanced types.

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ELECTRONIC MEASURING INSTRUMENTS

TRACING AN ELECTRONIC CONTOURING SYSTEM

From Idea to Application

One way to machine a complex shape is to copy a mechanical template. Starting with this simple concept, Author Jeudon carries through with the analysis, design, and application of the S.E.A. Duplicatron, an electronic contouring system. Using the systems approach, he establishes the mechanical requirements, analyzes them to determine control system configuration, investigates dynamic performance, instruments the computing and control networks, and applies the contouring system to a vertical lathe. It is immediately obvious that machine design and control equipment design must be coordinated if the two are to function together as a duplicating system.

A. JEUDON
Societe d'Electronique et d'Automatisme, France

When a revolving workpiece is to be machined on a horizontal or vertical lathe, the mechanical problem is to trace the desired contour with the cutting edge of the tool at as close as possible to optimum cutting speed. There are several ways of doing this automatically (see *Automatic Machining —A View and A Preview*, CONTROL ENGINEERING, September 1955). The datum dimensions of the workpiece can be delivered to the input of the tool carriage servo-control unit by: playing back a recording of the tool position coordinates for the complete machining cycle; scanning a drawing with photocells and the associated optical control system; or tracing a mechanical template with some type of contour follower. At present, the last scheme is most popular from standpoints of both cost and accuracy. But even here there are further choices to make. Should it be a completely hydraulic system, pneumatic-hydraulic, electronic, or electromechanical? All types are being used successfully. This discussion is restricted to the analysis and design of an electronic contour following system, chosen because of the ease of manipulating information and computing electronically.

The arrangement is shown in Figure 1. The contour follower and the tool are rigidly connected, and describe exactly parallel paths. This assembly is driven in the longitudinal and traverse directions with respect to the lathe spindle axis by means of the two motors, 1 and 2. The machining problem is solved when the contour follower is controlled so that it exactly follows the template.

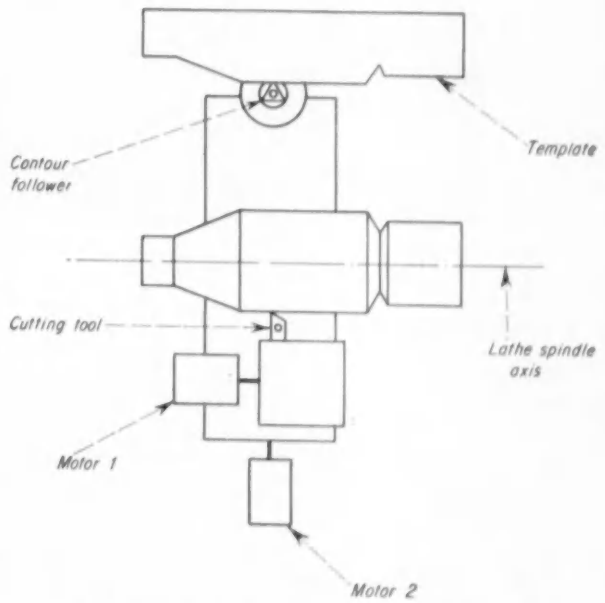


FIG. 1. Mechanical arrangement of contouring system.

A simple, widely-used method is to drive motor 1 at a constant speed, and apply feedback control only to the traversing motor 2, at right angles to the lathe bed. In this case, the tool holder is

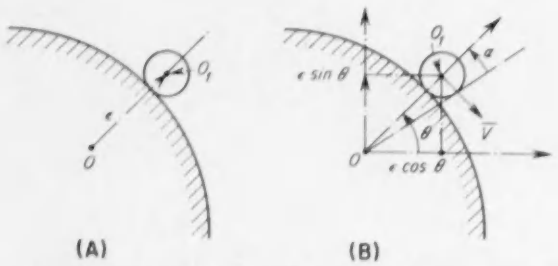


FIG. 2. (A) The follower is deflected by the template. (B) Appreciable friction introduces an angle α, the angle of friction.

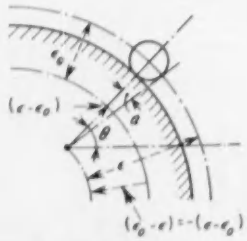


FIG. 3. If the follower does not deflect the proper amount, a position error results.

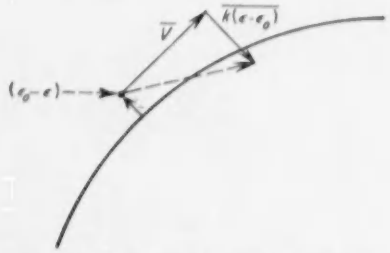


FIG. 4. Position order acts to reposition the follower with respect to the template.

tilted with respect to the lathe bed to make it possible to machine right-angle shoulders. This method has several disadvantages: cutting speed varies with resultant decreased efficiency; and it is impossible to machine some types of profiles.

In the system discussed here, both motors are servo-controlled, and the contour follower traces the template at a constant curvilinear speed. This method requires a follower that is sensitive in two perpendicular directions. How a four-coil impedance bridge accomplishes this will be described later.

SYSTEM ANALYSIS

Figure 2A shows the contour follower in contact with the template. 0 represents the free position of the follower, while 0_1 represents the actual position of the follower in contact with the template. Thus

$$\overline{|00_1|} = \epsilon$$

represents the follower displacement under the thrust of the template.

If the return force is independent of direction (effectively the case in practice), and if the contact is perfectly smooth, the vector $\overline{00_1}$ is at right angles to the template. But if the friction is not negligible, $\overline{00_1}$ makes an angle of plus or minus α with the perpendicular, which is equal to the friction angle, Figure 2B. If friction is constant, the angle is constant as long as direction does not change.

The contour follower delivers two electrical voltages proportional to the projections of $\overline{00_1}$ on the fixed axes,

$$\epsilon \cos\theta \text{ and } \epsilon \sin\theta$$

Therefore, the functions describing the tangent to the template at the contact point will be

$$\cos\left[\theta \pm \left(\alpha + \frac{\pi}{2}\right)\right]$$

$$\sin\left[\theta \pm \left(\alpha + \frac{\pi}{2}\right)\right]$$

Then, if the inputs to the two motor speed-control loops are as follows:

$$V\cos\left(\theta - \alpha - \frac{\pi}{2}\right) = V\sin(\theta - \alpha) \qquad (1)$$

and

$$V\sin\left(\theta - \alpha - \frac{\pi}{2}\right) = -V\cos(\theta - \alpha) \qquad (2)$$

the tool holder (and the contour follower) will be driven parallel to the template at a speed of magnitude V. If the input signals are

$$V\cos\left(\theta + \alpha + \frac{\pi}{2}\right)$$

and

$$V\sin\left(\theta + \alpha + \frac{\pi}{2}\right)$$

operation is identical, but direction is reversed.

Thus if there is no time delay, these simple orders are sufficient to drive the contour follower along a path parallel to the template. But to obtain the desired accuracy, a positioning order that maintains constant follower displacement is superimposed on the speed orders. If desired follower displacement is ϵ_o, then the position error, Figure 3, is

$$\epsilon_o - \epsilon$$

and the projections on the two axes are approximately equal to

$$(\epsilon_o - \epsilon)\cos(\theta - \alpha)$$
$$(\epsilon_o - \epsilon)\sin(\theta - \alpha)$$

The simplest way to cancel this variation is to superimpose the following orders on the speed-control orders as given by Equations 1 and 2:

$$K(\epsilon - \epsilon_o)\cos(\theta - \alpha) \qquad (3)$$
$$K(\epsilon - \epsilon_o)\sin(\theta - \alpha) \qquad (4)$$

where accuracy is independent of machining speed for a sufficient bandwidth if

$$K = kV$$

Thus if $(\epsilon - \epsilon_o)$ is small, the superposition of the position orders on the speed-control orders is equivalent to rotating the speed vector through a small angle equal to $k(\epsilon - \epsilon_o)$ radians. The action is similar to that of a driver who adjusts the steering

wheel slightly to reposition the car with respect to the road, Figure 4.

The system can be represented by the block diagram of Figure 5. The solid-line portion is identical to the functional diagram of a classic control system that simultaneously receives a position order and a velocity order. Note, however, that V, X and $(\epsilon - \epsilon_o)$ are vector quantities, each representing two components, one component along each of the two machine axes. Thus, some of the elements shown in the block diagram actually represent two pieces of equipment in the instrumented system; for example, the block *M* represents two motors. It is also incorrect to consider the system as a juxtaposition of two control systems, each represented by this diagram. Both loops interact at the template and computer levels, and it is impossible to study their respective performances independently. This is shown in Figure 6, which includes the two signal channels and the details of the various functions.

The dotted-line portion of Figure 5 indicates the geometric operations performed by the template and the follower. The three blocks A, *B*, and C do not represent any particular elements in the system, but rather schematize the various functions performed by the template, follower, and computing networks. Therefore it is necessary to introduce an intermediate variable, s, representing the curvilinear coordinate of the point of contact between the follower and the template, measured relative to an arbitrary origin. Block A expresses the follower position (magnitude of deviation of the control system) in terms of this intermediate variable s. Given s and the template, block *B* computes the position order *X* in terms of its two projections

$$x = f_1(s) \tag{5}$$

$$y = f_2(s) \tag{6}$$

where f_1 and f_2 are the parametric equations of the template profile.

Block *B* calculates the direction that must be assigned to the velocity order (tangent to the template). This direction is related to the control

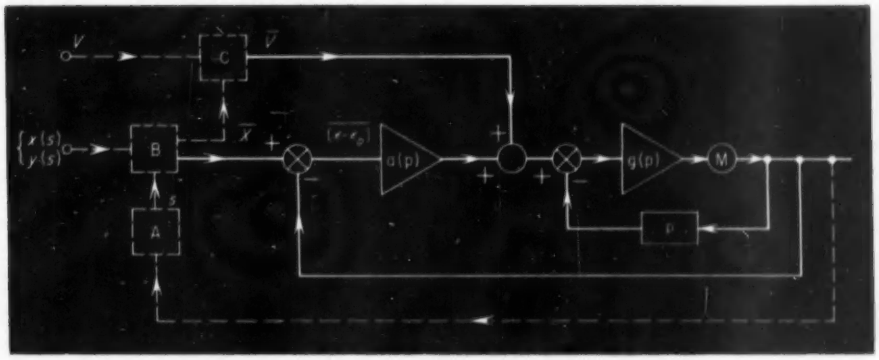


FIG. 5. Contouring system block diagram.

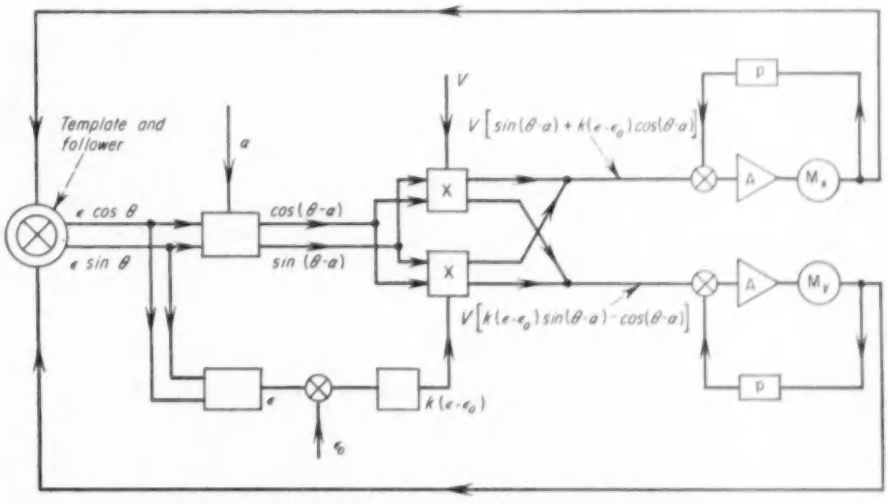


FIG. 6. Block diagram of complete integrated two-axis system.

system deviation and the shape of the template, so that the two perpendicular velocity components can be expressed by

$$\sin(\theta - \alpha) = \frac{d}{dt} f_1(s)$$

$$-\cos(\theta - \alpha) = \frac{d}{dt} f_2(s)$$

Block C calculates the velocity order $\overline{V}$ on the basis of the last two relationships and the modulus V, the desired tangential velocity along the template. Thus, the only external orders given to the system are the shape of the curve that is to be cut, and the tangential following velocity. The control system can be thought of as an analog computer that implicitly solves the following system of equations:

$$x = f_1(s)$$
$$y = f_2(s)$$
$$\frac{ds}{dt} = V$$

DYNAMIC PERFORMANCE

Going on the practical assumption that coupling two control systems with identical dynamic response does not complicate the theoretical analysis of performance of the composite system, it can be shown that in this case the analysis reduces to that of a single control system.

Assume for simplicity that the geometric transformations produced by $\cos(\theta - \alpha)$ or by $\sin(\theta - \alpha)$ are not accompanied by appreciable time lags. Then designate the closed-loop transfer function of each speed-control system by $g(p)$, and the transfer function of the elements (common to both channels) that generate the error quantity $(\epsilon - \epsilon_o)$ by $a(p)$. The transfer function of a system with two degrees of freedom can be obtained by recognizing that the angle $(\theta - \alpha)$ is a quantity introduced at each instant by the template, and is therefore independent of the dynamic behavior of the control system. Therefore this angle is considered a time-invariant quantity.

In the absence of a position error (ϵ equals ϵ_o) the trajectory of the follower is defined by the following relationships:

$$X = V \sin(\theta - \alpha) \frac{g(p)}{p} \tag{7}$$

$$Y = -V \cos(\theta - \alpha) \frac{g(p)}{p} \tag{8}$$

When there is a position error, an error signal is generated and the trajectory is defined by:

$$X = V[\sin(\theta - \alpha) + K(\epsilon - \epsilon_o)\cos(\theta - \alpha)\, a(p)] \frac{g(p)}{p} \tag{9}$$

$$Y = V[-\cos(\theta - \alpha) + K(\epsilon - \epsilon_o)\sin(\theta - \alpha)\, a(p)] \frac{g(p)}{p} \tag{10}$$

The difference between the trajectory defined by Equations 7 and 8, and the trajectory defined by Equations 9 and 10 appears at the follower as a position error with the following components:

$$\epsilon_x = V K (\epsilon - \epsilon_o) \cos(\theta - \alpha)\, a(p) \frac{g(p)}{p} \tag{11}$$

$$\epsilon_y = V K (\epsilon - \epsilon_o) \sin(\theta - \alpha)\, a(p) \frac{g(p)}{p} \tag{12}$$

Since ϵ_x and ϵ_y are projections of ϵ along the axes,

$$\epsilon = \epsilon_x \cos(\theta - \alpha) + \epsilon_y \sin(\theta - \alpha) \tag{13}$$

Substituting Equations 11 and 12 in Equation 13 gives

$$\epsilon = V K (\epsilon - \epsilon_o) \frac{a(p)\, g(p)}{p}$$

Therefore, solving for ϵ gives

$$\epsilon = \epsilon_o \frac{V K a(p)\, g(p)\, (1/p)}{1 - V K a(p)\, g(p)\, 1/p)} \tag{14}$$

This can be recognized as the conventional response of a control system in which the single variable ϵ_o is the input quantity. Since this quantity is fixed, the position control system functions as a deflection regulator. From a stability point of view, this is a single-variable control system with the following open-loop transfer function:

$$V K a(p)\, g(p)\, (1/p)$$

In practice, it is possible to choose either a single compensating loop acting on the modulus of the error [correction of $a(p)$] or two identical networks, each acting on one of the speed-control systems [correction of $g(p)$].

SYSTEM DESIGN

The most critical component in the system is the contour follower, since the performance of the whole unit depends on its efficiency. It should be

- sensitive—to detect motions of a few microns
- accurate—to ensure efficient operation of the prediction loop
- reliable—to avoid frequent adjustments
- sturdy—to withstand abuse of shop service

The element used in this system is shown in Figure 7. It consists of four magnetic coils mounted on a specially designed magnetic core. The flux path of each coil closes through a movable magnetic element E, which is integral with the contour follower. The coils are connected in a bridge and supplied from a 1,000 cps ac source. In the neutral position the two bridge legs are balanced. Any change in the position of E changes the armature gap distribution so that voltages are generated at X or Y.

Since E moves very little, these generated voltages are substantially proportional to changes in position. The accuracy of this relationship depends essentially on the support. The latter is designed so that the link joining E to the contour follower can move only in a parallel plane. In addition, the return-to-zero force is independent of the direction of motion.

Regardless of its strength, no contour follower can resist the thrust of the tool-holder against the template in the event of an incorrect operation. Therefore, safety devices must be included that will stop the drive motors when follower displacement exceeds

normal limits. Under normal service conditions, average follower deflection is about $\frac{1}{64}$ in., with a corresponding force on the template of about 1 oz.

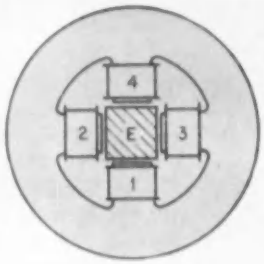
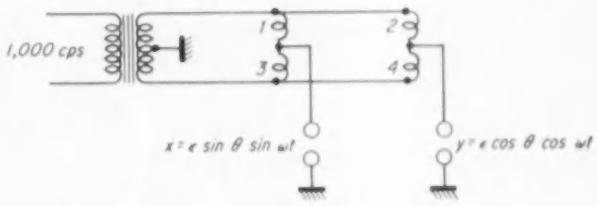


FIG. 7. Contour follower and its bridge circuit.



How to Determine $(\epsilon - \epsilon_o)$

The voltages $\epsilon \cos \theta \cos \omega t$ and $\epsilon \sin \theta \cos \omega t$ from the contour follower bridge are in phase (ω equals 2π 1,000). To obtain the magnitude of ϵ, the carrier of one of the signals is shifted in phase by 90 deg, and then the two signals are summed, Figure 8. This gives a voltage that can be expressed by

$$\epsilon \cos (\omega t + \theta)$$

which gives ϵ after detection. A resistance bridge is used to obtain the algebraic sum

$$\epsilon - \epsilon_o$$

This bridge is arranged so that the dc voltage corresponding to ϵ_o can be adjusted at will. Conventional techniques are used throughout.

How to Determine Cos $(\theta - a)$ and Sin $(\theta - a)$

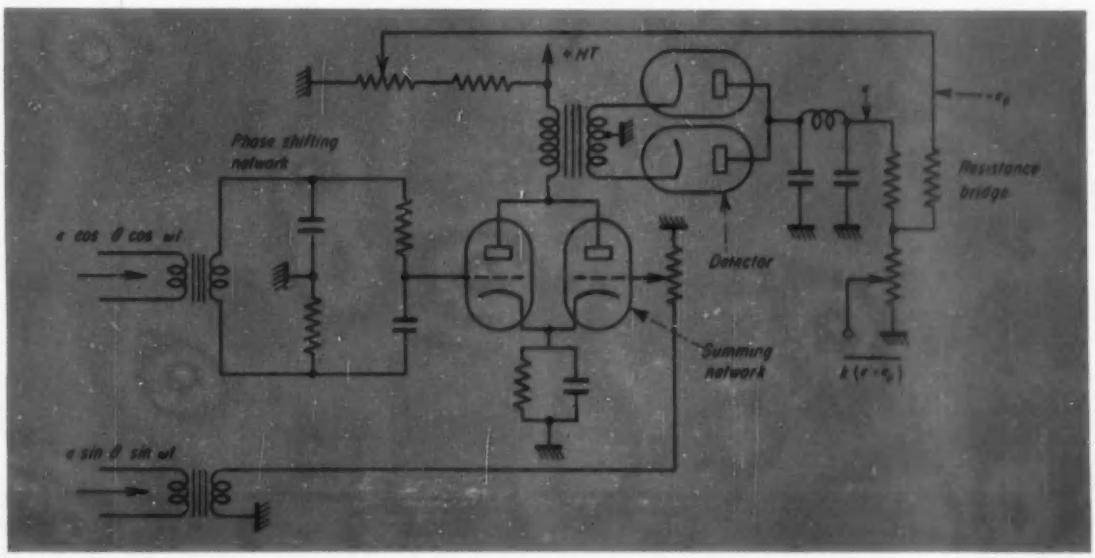
The angle a can be introduced quite easily. For instance, this can be done by shifting the phase of the voltage $\epsilon \cos (\omega t + \theta)$, already obtained for determining ϵ, by the angle a, with cos $(\theta - a)$ and sin $(\theta - a)$ being subsequently derived from two phase detectors having references of $E \cos \omega t$ and $E \sin \omega t$ respectively.

It could also be introduced by means of a simple resistance matrix operating on the values of cos θ and sin θ obtained previously with a linear combination. Because the template and contour follower are made of highly polished steel and are well lubricated, the friction angle is very small and can be neglected. When the template is made of a material with a significant coefficient of friction, such as wood or plaster, the angle a can be handled without undue complications.

With this simplification in mind, notice that ϵ is always almost equal to the desired follower deflection ϵ_o. Therefore, as a first approximation, it can be assumed that the voltage outputs of the contour follower coils represent the functions that describe the perpendicular to the template (within a constant factor). This causes a slight amplitude modulation of the speed vector proportional to the error in position. This does not affect the tangential component of V, and it is possible to approximately compensate the normal component by using the nonsymmetrical characteristic of the multiplier.

With these simplifications, the describing functions are obtained directly from two amplifiers connected to the contour follower bridges. Feedback circuits included in these amplifiers make gain independent of the effects of aging on tube amplification.

FIG. 8. Computing circuit for determining $(\epsilon - \epsilon_o)$



How to Determine $(\epsilon - \epsilon_o)$ Cos θ and $(\epsilon - \epsilon_o)$ Sin θ

Determining these two intervening terms in the positional loop requires circuits capable of multiplying two variables, one of which (sin θ or cos θ) is in the form of an amplitude-modulated 1,000 cps carrier, while the other $(\epsilon - \epsilon_o)$ is already demodulated. Highly accurate multipliers are not necessary, but since all sign combinations are possible, the zero point must be stable. Under these conditions, a symmetrical circuit using two variable-μ tubes is satisfactory, Figure 9. The cos θ ac signal is applied symmetrically to the cathodes, while the $(\epsilon - \epsilon_o)$ dc voltage varies the grid bias of one of the tubes. The plates of the tubes are connected to a push-pull transformer, and the secondary winding delivers a voltage proportional to the product.

Actually, this multiplier is slightly nonsymmetrical with respect to the sign of $(\epsilon - \epsilon_o)$. By proper arrangement of the connections (interaction combinations) it is possible to approximately compensate for this error and for the one caused by the amplitude modulation of the vector V.

How to Determine the Speed Orders

Since each of the component terms have been determined, the speed orders

$$V\,[\sin\theta + k\,(\epsilon - \epsilon_o)\cos\theta] \text{ and } V\,[k\,(\epsilon - \epsilon_o)\sin\theta - \cos\theta]$$

can be obtained by a simple summation. After these sums are taken, they are applied to the input of the last amplifying stage. Again amplifier gain is stabilized by appropriate feedback. The proper sign is then detected with reference to phase by a conventional balanced detector followed by a double-section filter that removes all trace of the 1,000 cps carrier.

This summation stage includes a relay-controlled switch that makes it possible to follow the template in either direction by changing the signs of V cos θ and V sin θ. Also, two potentiometers are provided for adjusting V to the desired feed speed.

Power Stages and Speed-Control System

After the two speed orders are computed, they are carried out by two split-field, thyratron-controlled, series-wound motors. This type motor is particularly suited to reversing service and the Alsthom design, especially built for the application, is the one selected for this system. Well-built motors are essential in contouring equipment, for when machining a shoulder at right angles to the axis of the workpiece, for example, the longitudinal drive motor should stop instantaneously. Of course, this is impossible, but, to approach it, the motor must be able to withstand a very high instantaneous overload current. Actually, system response is as good as possible considering the limiting factor of 50 cps ac supply. The motors can be stopped in somewhere between 1/100 and 1/50 sec.

The thyratrons are pulse-controlled. The pulses are obtained by controlling the grid bias of an amplifying stage saturated by a 50-cps voltage, and the derivative of the variable-width square wave is used to control the thyratron grids, Figure 10.

Semi-Automatic Operation

To make it easy to contact the template, and to permit certain machining operations without a template, the system provides for "semi-automatic" operation. In this mode, it is possible to give the tool carriage an arbitrary speed and direction.

Since the follower is not contacting the template, it produces no signal. Instead, a two-phase, resolver-

FIG. 10. Thyratron circuit for controlling split-field series motor.

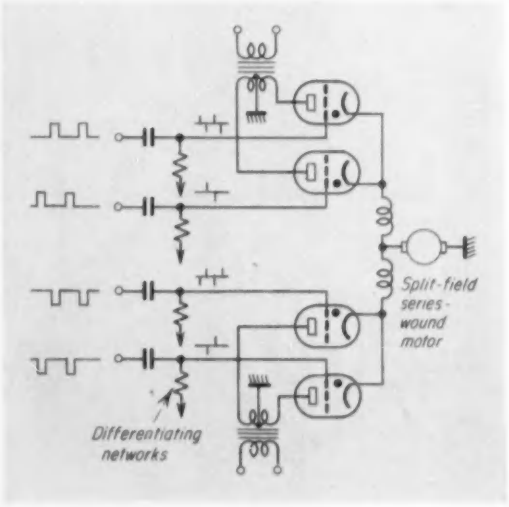
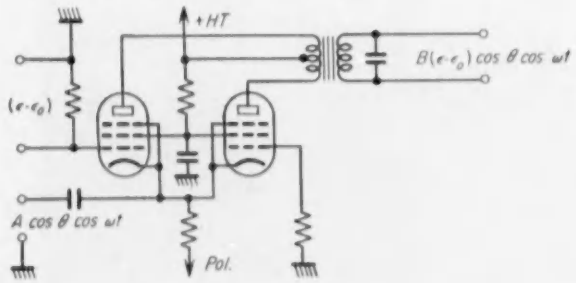


FIG. 9. Multiplying circuit for obtaining $(\epsilon - \epsilon_o)$ cos θ and $(\epsilon - \epsilon_o)$ sin θ.



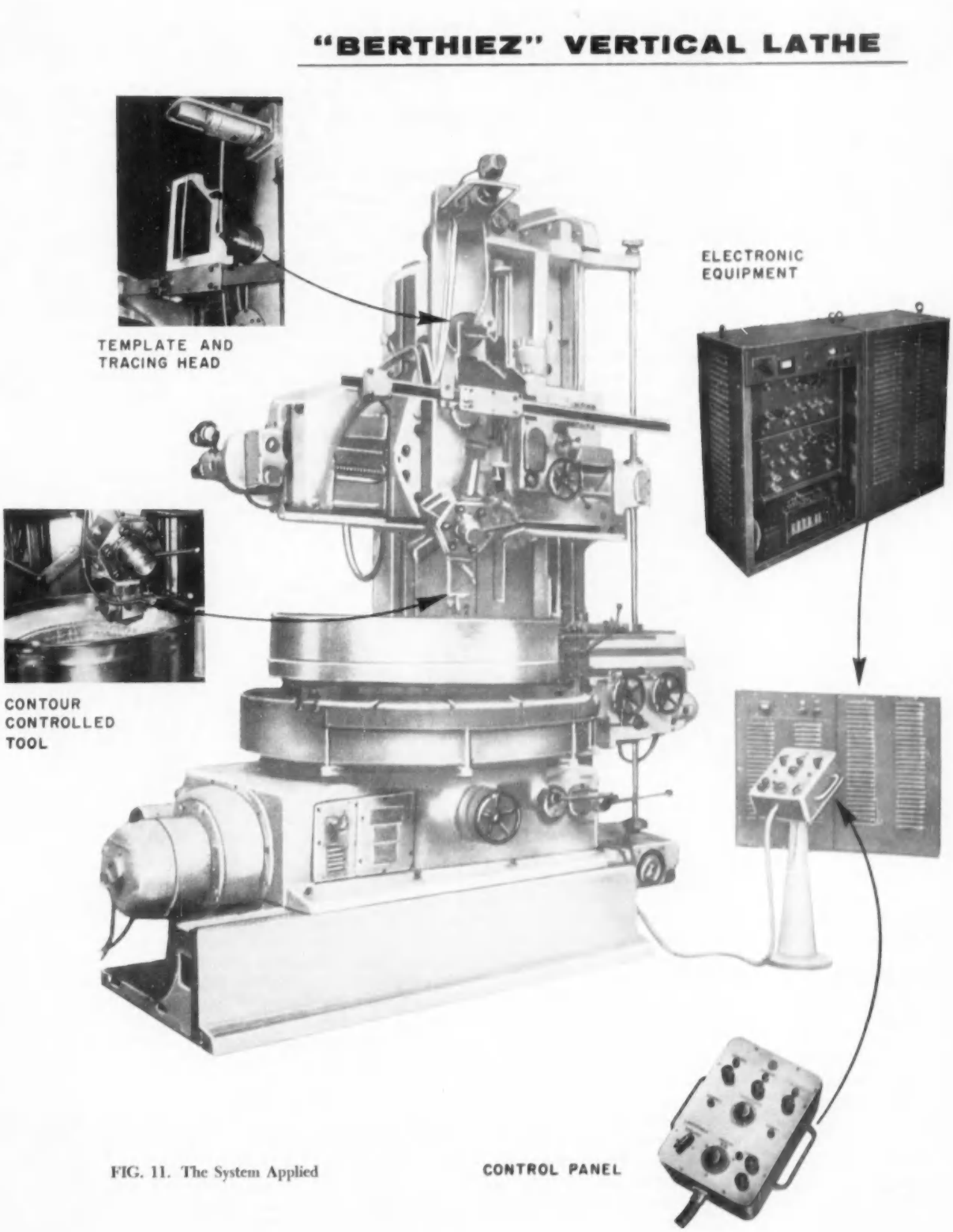


FIG. 11. The System Applied

type component is used to generate two voltages having the form

$$E \cos \psi \cos \omega t$$
$$E \sin \psi \cos \omega t$$

where ψ is the angle of the rotor with respect to a given reference. The angle is set by a dial on the control panel, calibrated from 0 to 360 deg. The tool then moves at a constant speed at the set angle.

If the contour follower contacts the template when on semi-automatic, a safety device immediately switches the machine to automatic operation and the system executes duplicating work as long as the follower remains in contact.

SYSTEM APPLICATION

This contouring system has been used on many types of machines. The one selected for this discussion is a vertical lathe manufactured by the Société Anonyme des Anciens Établissements Charles BERTHIEZ, Figure 11. The lathe consists of a vertical slide mounted on the upright and a cross slide mounted on an arm. The latter is equipped with drive motors for duplicating work. The normal feed mechanisms have not been changed; slide and carriage motion are obtained by rotating a nut with respect to a fixed screw, integral with the arm or carriage. During contouring, the screws rotate and the nuts are stationary. This simple solution increases lathe flexibility whether it is used in the automatic or manual mode. The contouring motors are small, so that it is possible to mount one on the arm and the other on the tool carriage.

The contour follower and tool are rigidly fastened to the tool carriage. The contour follower and its support are designed so that they withdraw automatically when the lathe is used with conventional control. This prevents accidental contact with the template when the copying equipment is not switched on. The template is mounted on a supporting strip fastened to the slide and the arm (rigidly to the arm only, since the slide moves).

The Lathe as Part of a System

It should be emphasized that high-precision contouring equipment cannot be developed without close collaboration between the machine-tool builder and the control equipment manufacturer. A duplicating lathe forms a whole system. Although the user may consider duplicating to be an accessory function, the manufacturer cannot, since the quality of the equipment he produces depends largely on his comprehension of the coordinated function of the lathe and the contouring system. While most of the fundamental defects of machine structure are identical, whether the machine is manually or automatically controlled (resilience, backlash, coulomb friction), the machine reacts differently under automatic control and some of the defects may be corrected while others are amplified.

The two most important mechanical properties of a machine are rigidity and minimum backlash. The machine structure must be rigid enough so that the relative geometric positions of the contour follower and template on one hand, and of the contour follower and tool on the other, are absolutely stable. This touches on a basic principle of copying work. It is useless to accurately control the contour follower if the tool does not travel an exactly parallel path with respect to the workpiece. In addition, the kinematic chains must be adjusted for minimum backlash, for although a small amount of backlash has no effect on stability, it does influence surface finish.

In practice, satisfactory results are being obtained with clearances of about 0.0079 in. Errors are held to within 0.0004 in., and good surface finishes are obtained. Coulomb friction, combined with resilience in the transmission, also affects performance.

Finally, frame vibrations, either from the lathe itself or from external sources, are liable to be recorded by the contour follower, which in turn will transmit them to the computer. These vibrations are particularly harmful if their fundamental frequency or harmonics are near the frequency of the line current. In the thyratron stage this can cause beat oscillations in the servo bandwidth.

The Machining Outlook

In principle, any profile can be machined with this system, since it can cut and move at any angle and direction, and the complexity of the configuration is limited only by the shape of the cutting tools. It is particularly well suited for machining curved or complex surfaces, since specially designed tools are not necessary. It is also capable of duplicating pieces having sharp, projecting, or recessed angles; for example, T-shaped annular grooves in casing walls.

Copying equipment is economical for certain types of mass production, where part interchangeability can be obtained (even if production is interrupted for several months) as long as the template is the same and it is properly mounted on the machine.

Electronic duplicators on vertical lathes have saved money for the aircraft industries in the machining of complex pieces, such as turbojet casings. A high-precision workpiece approximately 39 in. in diameter and consisting of an internal tapered section and various outer flanges has been produced in large numbers by contouring techniques. Other jobs include machining flywheels, tire molds, and blanks for spur or bevel gears.

ACKNOWLEDGEMENT

The authors would like to mention that the work on electronic equipment planned and developed by S.E.A. was initiated at the request of the Laboratoire Central de l'Armement (Ordnance Laboratory). They would also like to thank the Sté Anonyme des Anciens Établissements Charles BERTHIEZ for permission to publish the photographs and technical details of their vertical lathe.

Selecting Power-Control Valves

II—THEIR DESIGN AND PERFORMANCE

Last month the authors described the characteristics of hydraulic and pneumatic power-control valves. Now they conclude their discussion with an examination of oil and air designs for valve-controlled servo drives. Accompany them on an analytical tour of the respective characteristics to see how they arrive at the conclusion that a position servomechanism can be about 45 times faster with hydraulic fluid than with compressed air for the same load mass and supply pressure. Interim computations in each system have been paralleled for convenient comparison.

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To demonstrate and compare power-control valve design procedures for oil and for air, let a valve-controlled ram (servomotor) like that in Figure 1 be used to position a 500-lb mass within a maximum stroke of plus or minus 3 in. in a system like that in Figure 2. Assume that the measuring means and the amplifier and valve actuator have negligible lags (possible with simple linkages, but generally not with electric transducers).

System specifications: a maximum load acceleration of 500 in./sec² at zero velocity with a 500-lb external opposing load; a maximum steady velocity of 3 in./sec with a steady 500-lb external opposing load; a fluid supply pressure of 800 psi; a standby power loss (load motionless, external load zero) not to exceed 0.5 hp. The mass-loaded servomotor should have a damping ratio of at least 0.5 to make possible the best closed-loop performance[1].

Ram Area Calculation

If the valve is displaced far enough from its neutral position, the full supply pressure is available to move the ram when its velocity is low. Based on acceleration and external load specifications, summing forces (Newton's Second Law) gives

$$P_s A = m \frac{d^2 Y}{dt^2} + b \frac{dY}{dt} + L$$

or, at zero velocity,

$$A = \frac{(1.3)(500) + 0 + 500}{800} = 1.44 \text{ in.}^2$$

A commercially available equal-area double-acting cylinder with a net working area of 1.50 in.² and a total stroke of 6.5 in. has a measured viscous damping coefficient of 1.5 lb sec/in. Load damping measures 15.9 lb sec/in. Thus, the pressure across the ram, P_m, that is needed for 3 in./sec. maximum

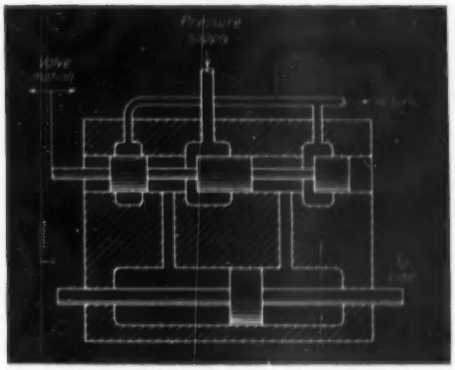

FIG. 1. A valve-controlled ram servomotor.

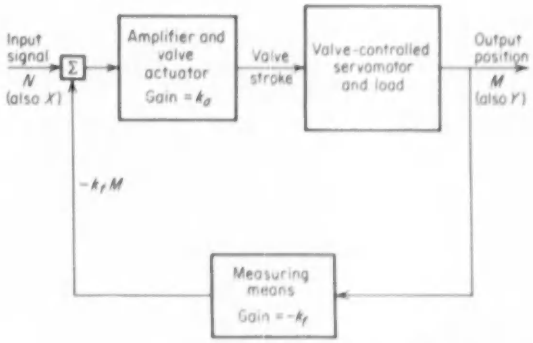

Fig. 2. Ram positioning servo system.

steady velocity with 500-lb external opposing load is:

$$P_m A = b\left(\frac{dY}{dt}\right)_{max} + L_{max}$$

or

$$P_m = \frac{(17.4)\,(3) + 500}{1.50} = 368 \text{ psi}$$

The dynamic characteristics of the valve-controlled ram for "small" changes of all variables are[2]:

$$\left(\frac{k_2 m}{k_2 b + A^2}\right)\frac{d^2\left(\frac{d\Delta Y}{dt}\right)}{dt^2} + \left(\frac{k_2 m + k_3 b}{k_2 b + A^2}\right)\frac{d\left(\frac{d\Delta Y}{dt}\right)}{dt}$$

$$+ \frac{d\Delta Y}{dt} = \frac{k_1 A\,\Delta X - k_3\frac{d\Delta L}{dt} - k_2\Delta L}{k_2 b + A^2}$$

Damping Ratio

The damping ratio, ζ_s, of the servomotor is given by the following equation, or by the graph in Figure 3:[2]

$$\zeta_s = \frac{k_2 m + k_3 b}{2\sqrt{k_3 m\,(k_2 b + A^2)}}$$

$$= \frac{\frac{k_2}{A}\sqrt{\frac{m}{k_3}} + \frac{b}{A}\sqrt{\frac{k_2}{m}}}{2\sqrt{\left(\frac{k_2}{A}\sqrt{m}\right)\left(\frac{b}{A}\sqrt{\frac{k_3}{m}}\right)} + 1}$$

(Continued on top of next page)

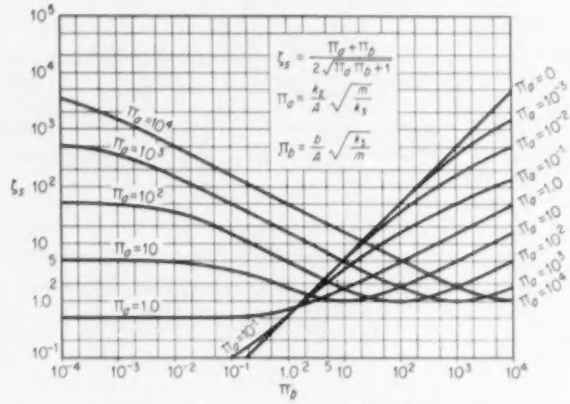

FIG. 3. Graph gives the damping ratio, ζ_s, of an hydraulic or pneumatic servomotor. Constants are defined in text.

HYDRAULIC

For oil, the fluid compliance is

$$k_3 = \frac{V_t}{2\beta}$$

where β is the bulk modulus of pure hydraulic fluid with no entrained air, which is 2.5×10^5 lb/in.^{2} Therefore,

$$\frac{b}{A}\sqrt{\frac{k_3}{m}} = \frac{17.4}{1.50}\sqrt{\frac{(3.25)\,(1.50)}{2(2.5\times10^6)\,(1.36)}}$$

$$= 3.18 \times 10^{-3}$$

assuming negligible volume in passages connecting valve to ram. Using the graph of Figure 3, for a damping coefficient, ζ_s, of 0.5,

$$\frac{k_2}{A}\sqrt{\frac{m}{k_3}} = 1.0, \text{ from which}$$

$$k_2 = A\sqrt{\frac{k_3}{m}} = (1.50)\,(2.5\times10^{-3})$$

$$= 3.75 \times 10^{-3} \text{ in.}^5\text{/lb sec}$$

As defined, $k_2 = C_1 + C_2$. For the ram motionless at the center with no load, the valve must be centered.

Assuming no leakage past the ram,

$$C_2 = 0$$

$$C_1 \leqq C_d\,Uw\sqrt{\frac{1}{P_s\,\rho}}$$

$$Uw = \frac{C_1}{C_d}\sqrt{P_s\,\rho}$$

$$= \frac{3.75\times10^{-3}}{0.65}\sqrt{800\times8\times10^{-5}}$$

$$= 1.46 \times 10^{-3} \text{ in.}^2$$

So, each of the four orifices would have an area of 0.00146 in.^{2} with valve centered. The quiescent power loss would be

$$\frac{P_s Q_q}{6{,}600} = \frac{Q_q}{8.25}$$

$$Q_q = 2\,C_d\,Uw\sqrt{\frac{P_s}{\rho}} \text{ in.}^3\text{/sec}$$

$$\frac{P_s Q_q}{6{,}600} = \frac{(2)\,(0.65)\,(1.46\times10^{-3})}{8.25}\sqrt{\frac{800}{8\times10^{-5}}}$$

$$= 0.73 \text{ hp}$$

which exceeds the specified 0.5 hp. Hence Uw must be reduced by one-third to 1.0×10^{-3} in.^{2}

To satisfy Uw C_1 must equal $\frac{2}{3}$ k_2; therefore, C_2 must equal $\frac{1}{3}$ k_2, or $C_2 = 1.25 \times 10^{-3}$ in.^{5}/lb sec. A by-pass capillary can be designed to provide C_2 because it is easier to control in manufacture than leakage past the ram, and permits adjustment.

Maximum Hydraulic Power . . . .

The maximum hydraulic power which must be supplied to the valve is

$$\frac{P_s Q_{max}}{6{,}600} = \frac{P_s\,C_d\,A_{o\,max}\sqrt{\frac{P_s}{\rho}}}{6{,}600}$$

(Continued on page 76.)

The closed-loop differential equation relating change of output position, ΔN, to change of input signal, ΔM (see Figure 2), is

$$\left(\frac{k_2 m}{k_2 b + A^2}\right)\frac{d^2(\Delta M)}{dt^2} + \left(\frac{k_2 m + k_2 b}{k_2 b + A^2}\right)\frac{d^2(\Delta M)}{dt^2} + \frac{d(\Delta M)}{dt} + \frac{k_1 A\, k_a\, k_f}{k_2 b + A^2}\,\Delta M = \frac{k_1 A\, k_a\, \Delta N - k_3 \dfrac{d(\Delta L)}{dt} - k_2 \Delta L}{k_2 b + A^2}$$

and in the steady state

$$(\Delta M)_{ss} = \frac{(\Delta N)_{ss}}{K_f} - \frac{K_2 (\Delta L)_{ss}}{A k_1 k_a k_f}$$

Although k_f can be adjusted to meet most requirements, $k_1 k_a k_f$ can cause system instability[2]. Large values of $k_1 k_a k_f$ reduce load sensitivity, but

$$K_l = \frac{k_1 k_a k_f A}{k_2 b + A^2}$$

should not exceed $0.45\omega_{ns}$, which is given by

$$\omega_{ns} = \sqrt{\frac{k_2 b + A^2}{k_2 m}}$$

NOMENCLATURE

- A — ram area, in.^{2}
- b — viscous damping in ram and load, lb sec/in.
- C_1 — valve characteristic — partial derivative of flow rate with respect to pressure, at operating point, in.^{5}/lb sec
- C_2 — laminar leakage flow coefficient, in.^{5}/lb sec
- D_c — capillary diameter, in.
- Δ — small change from initial steady condition.
- g — acceleration due to gravity, 386 in./sec^2
- k_1 — valve characteristic (flow sensitivity) — partial derivative of flow with respect to valve position, in.^{2}/sec.
- k_2 — equals $C_1 + C_2$
- k_3 — fluid compliance, in.^{5}/lb
- L — external load force, max. = 500 lb
- L_c — length of capillary passage, in.
- m — load mass, 500/386 = 1.36 lb sec^2/in.
- P_s — supply pressure, 800 psi
- R — gas constant, 2.47×10^6 in.^{2}/sec^2 deg F for air
- t_c — thickness of capillary passage, in.
- V_i — volume in one ram chamber (ram centered) plus one passage to valve, in.^{3}
- X or N — valve position (stroke from center), in.
- Y or M — ram position, in.
- ω_{ns} — natural frequency of uncontrolled servomotor
- ζ_s — servomotor damping ratio

PNEUMATIC

For air, the fluid compliance is

$$k_3 = \frac{V_i}{2kP_i}$$

where k = ratio of specific heats, 1.4 for air; and P_i = initial value of ram pressure, 539 psi abs. Then

$$\frac{b}{A}\sqrt{\frac{k_3}{m}} = \frac{17.4}{1.50}\sqrt{\frac{(3.25)(1.50)}{2(1.4)(539)(1.36)}} = 0.577$$

assuming negligible volume in passages connecting valve to ram. Using the graph of Figure 3, for a damping coefficient, ζ_s, of 0.5,

$$\frac{k_2}{A}\sqrt{\frac{m}{k_3}} \cong 0.5, \text{ from which}$$

$$k_2 = A\sqrt{\frac{k_3}{m}} = (1.50)(4.98 \times 10^{-2}) = 7.45 \times 10^{-2} \text{ in.}^5/\text{lb sec}$$

As defined, $k_2 = C_1 + C_2$. For the ram motionless at the center with no load, the valve must be centered.

$$C_1 = \frac{R T_s}{2 g P_i}\frac{\partial W_a}{\partial P_a} = \frac{(2.47 \times 10^6)(530)(5.7 \times 10^{-6})}{(2)(386)(540)} = 1.79 \times 10^{-2} \text{ in.}^5/\text{lb sec}$$

For a measured quiescent leakage flow of 0.001 lb/sec, the standby power to compress this flow rate isothermally from 15 psia to 815 psia is

$$\frac{W_q R T_s}{6{,}600\, g}(\ln 815 - \ln 15) = \frac{(0.001)(2.47 \times 10^6)(530)(6.71 - 2.71)}{(6{,}600)(386)} = 0.206 \text{ hp}$$

Although the allowable power drain is 0.5 hp, C_1 falls too far short of k_2 to make the valve intentionally open-centered. Besides, some production valves might have twice as much leakage flow as the valve measured.

Damping, therefore, is needed, and can be provided by a capillary passage connecting the two ends of the ram. The average velocity in the capillary must be low enough to avoid nonlinear "saturation" due to momentum effects[4]. A good rule is to make its cross-sectional area equal to that of the valve-to-ram passages. Matrix type capillaries can be adjusted to the resistance needed.

Maximum Pneumatic Power . . . .

The maximum pneumatic power which must be supplied to the valve may be calculated from the maximum flow W_a needed for a ram velocity of 3 in./sec when P_a is 650 psi and load force is 500 lb.

$$W_a = \frac{P_a g A}{RT}\left(\frac{dY}{dt}\right) = \frac{(650)(386)(1.5)(3.0)}{(2.47 \times 10^6)(530)} = 8.6 \times 10^{-3} \text{lb/sec}$$

(Continued on page 76.)

HYDRAULIC

where

$$A_{o\,max} = \frac{A\left(\frac{dY}{dt}\right)_{max} + C_2 P_{m\,max}}{C_d \sqrt{\frac{\rho}{(P_s - P_{m\,max})}}}$$

The maximum power thus calculated is 0.76 hp (compare the high standby power of 0.5 hp), but it is well to provide at least 100 per cent extra valve capacity ($A_{o\,max}$) to provide for transient demands.

Response . . . .

The servomotor's natural frequency is

$$\omega_{ns} = \sqrt{\frac{3.75 \times 10^{-3}\,(17.4) + (1.5)^2}{9.75 \times 10^{-6}\,(1.3)}}$$

$$= 428 \text{ rad/sec}$$

so that

$$K_l = 0.45\,(428) = 192 \text{ sec}^{-1}$$

and

$$k_1 k_a k_f = \frac{k_2 b + A^2}{A}\,(K_l)$$

$$= \frac{3.75 \times 10^{-3}\,(17.4) + (1.5)^2}{1.5}\,(192)$$

$$= 288 \text{ in.}^2/\text{sec}$$

The value of k_1 is[3]

$$k_1 = 2\,C_d\,w\sqrt{\frac{P_s}{\rho}}$$

for the zero flow zero load condition, and depends on the port width w, which can be chosen for reasonable values of k_1, k_a, and k_f. The port width often affects the simplicity of valve fabrication.

The steady-state load sensitivity is

$$\left(\frac{\Delta M}{\Delta L}\right)_{ss} = -\frac{k_2}{k_1 k_a k_f A}$$

$$= \frac{-3.12 \times 10^{-3}}{(288)\,(1.5)}$$

$$= 7.21 \times 10^{-6} \text{ in./lb}$$

The response of the output shaft to a step change in input signal will overshoot by about 20 per cent, and the time to first crossover will be[1]

$$T_1 \leqq \frac{2.5}{\omega_{ns}} \leqq \frac{2.5}{428} \leqq 5.85 \times 10^{-3} \text{ sec}$$

Thus, the hydraulic system is about 45 times as fast as the pneumatic for the same load mass and supply pressure.

Increasing Pneumatic Sensitivity

As calculated, the hydraulic system turns out to be about 1,000 times as "stiff", $\Delta M/\Delta L$, as the pneumatic system for a steady load, L. Instead of the by-pass capillary, the resistance and tank scheme devised by Levinstein[5] can be used for damping. This so-called "transient flow stabilizer" was tested experimentally[3], and with its use only the effects of C_1 appear in the load sensitivity equation and the pneumatic system stiffness can be increased by a factor of 40.

PNEUMATIC

and the power which would be required to compress air isothermally to 815 psia at this rate would be

$$hp_{max} = \frac{W_{a\,max}\,RT_s}{6{,}600\,g}\,(\ln 815 - \ln 15) = 0.95\,hp$$

It is seldom necessary to compress air at this peak rate because of the tremendous storage capacity of even relatively small storage tanks.

Response . . . .

The servomotor's natural frequency is

$$\omega_{ns} = \sqrt{\frac{7.45 \times 10^{-2}\,(17.4) + (1.5)^2}{2.48 \times 10^{-3}\,(1.3)}}$$

$$= 9.2 \text{ rad/sec}$$

so that

$$K_l = 0.45\,(9.2) = 4.13 \text{ sec}^{-1}$$

and

$$k_1 k_a k_f = \frac{k_2 b + A^2}{A}\,(K_l)$$

$$= \frac{7.45 \times 10^{-2}\,(17.4) + (1.5)^2}{1.5}\,(4.13)$$

$$= 9.78 \text{ in.}^2/\text{sec}$$

The value of k_1 is[3]

$$k_1 = 2\,C_d\,w\sqrt{\frac{P_s}{\rho}}$$

for the zero flow zero load condition, and depends on the port width w, which can be chosen for reasonable values of k_1 k_a, and k_f. The port width often affects the simplicity of valve fabrication.

The steady-state load sensitivity is

$$\left(\frac{\Delta M}{\Delta L}\right)_{ss} = -\frac{k_2}{k_1 k_a k_f A}$$

$$= \frac{-7.45 \times 10^{-2}}{(9.78)\,(1.5)}$$

$$= 5.08 \times 10^{-3} \text{ in./lb}$$

The response of the output shaft to a step change in input signal will overshoot by about 20 per cent, and the time to first crossover will be[1]

$$T_1 \leqq \frac{2.5}{\omega_{ns}} \leqq \frac{2.5}{9.2} \leqq 0.272 \text{ sec}$$

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THE GIST: Deliberate introduction of nonlinear elements into a control system can make the system simpler, smaller, and more economical; it can compensate for inherent nonlinearities; or—and here is the major emphasis of this article—it can, by means of the relatively new and advanced technique of optimizing or programming an on-off system, enable the system to reach zero error in minimum time without overshoot following a disturbance.

NONLINEARITY IN CONTROL SYSTEMS

PART 3—DELIBERATELY NONLINEAR SYSTEMS

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Nonlinearity in control systems often leads to continuous oscillations, less accurate control, and variations in the time it takes for the system to return to equilibrium following a disturbance. Thus inherent nonlinearities are considered undesirable, and strenuous efforts are being made to eliminate or minimize their effects.

Most control components, such as motors and valves, have some linear working range. A system could be designed for this range and thus avoid the pitfalls of nonlinearity, but then components would be operating below their full ratings. Stated another way, this would mean using oversize motors and valves. These increase system size and cost, and so the designer tries to get along with nonlinearities and perhaps even use them to advantage.

Nonlinear elements may be deliberately introduced into control systems for three basic reasons:

- to make the system simpler, more economical, and smaller
- to compensate for inherent nonlinearities
- to "optimize" system performance.

Simple On-Off Systems

The on-off, or two-position, regulator is the most common type of deliberately nonlinear control system. A familiar example is the household thermostat, which turns a furnace on and off according to temperature measured by a bimetallic strip. Here the temperature actually oscillates around the desired setting with a period and amplitude that depend on system thermal lags and dead space between contacts. If it gives adequate performance, the on-off controller can be an economical and simple solution to the control problem. Some industrial applications use similar temperature controllers.

Other applications of the simple on-off controller include control of liquid level, wherein solenoid-operated valves fill or empty a tank; control of refrigerators, air compressors, and water pumps; and regulation of speed and voltage. Relay servos, controlled by radio signals, are used for remote steering of small airplanes and boats.

In general, these applications are characterized by rather mild accuracy requirements, low power levels, and limitations on size, weight, or cost. Difficulty with simple on-off control arises when high accuracy must be combined with stability, and when components that can stand the strain of frequent full-on to full-off operation must be found.

NONLINEAR COMPENSATION

Deliberate introduction of an appropriate nonlinear element into an already nonlinear control system can improve overall system behavior. For example, consider a process system. Here the nonlinear relations that exist between fluid flow and

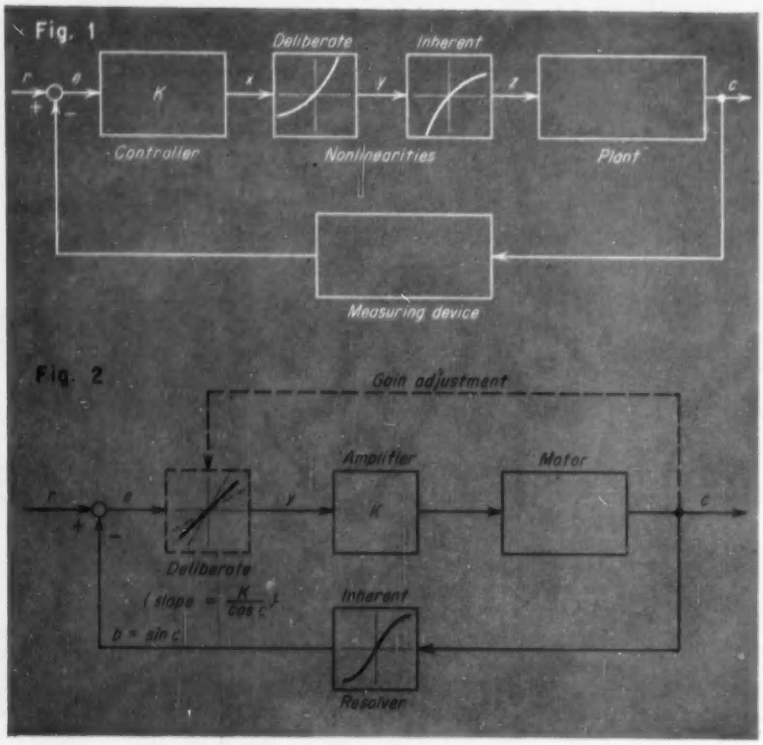


FIG. 1. This closed-loop system contains an inherent nonlinearity in the forward path. This arrangement can be linearized by inserting a deliberate nonlinearity, $y = f(x)$, in the forward path so that $z = Kx$.

FIG. 2. In this case the inherent nonlinearity, due to essential use of the resolver, appears in the feedback path. Here, the system gain depends on the operating point or position of the output c. However, a deliberate nonlinearity, again in the forward path, corrects the system gain as a nonlinear function of output position.

pressure or valve position are a common source of difficulty. One solution is to select that relation between valve area and stem position which minimizes variations of loop gain with changing conditions. Alternatively, however, a nonlinear relation can be deliberately introduced; i.e., stem position can be made a nonlinear function of the actuating signal. This linearizes the overall system. Butterfly valves that control gas flow use linkages for this purpose.

The general procedure for introduction of deliberate nonlinearity to linearize a control system is shown in Figure 1. Here, if the system contains an inherent nonlinearity, $z = g(y)$ in the forward path, it may be possible to introduce a deliberate nonlinearity, $y = f(x)$, so that $z = Kx$. To find the function y it is only necessary to label the z-axis of the z-y plot with corresponding values of x, $x = z/K$, and turn the plot 90 deg to view y as $f(x)$.

Figure 2 shows a similar but more interesting situation. Here the inherent nonlinearity appears in the feedback path. This closed-loop arrangement is typical of a computer servomechanism that develops $c = \arcsin r$. The resolver generates a voltage proportional to the sine of the servo's output angle. Thus the resolver's sinusoidal nonlinearity is inherent, since it is essential to system operation.

Because the motor rotates until the error e is zero, the steady-state condition is

$$r = b = \sin c$$

as desired. However, without the deliberate nonlinearity the incremental loop gain is proportional to

$$\frac{db}{dc} = \cos c$$

and therefore gain varies with changes in the operating point. Without insertion of the deliberate nonlinearity the system would be sluggish and inaccurate when c approached 90 deg, even though it might be satisfactory near zero deg. But an appropriate nonlinearity introduced in the forward path of the feedback loop makes the gain independent of the operating point. This can be obtained by making the forward gain

$$\frac{dy}{de} = \frac{1}{\cos c}.$$

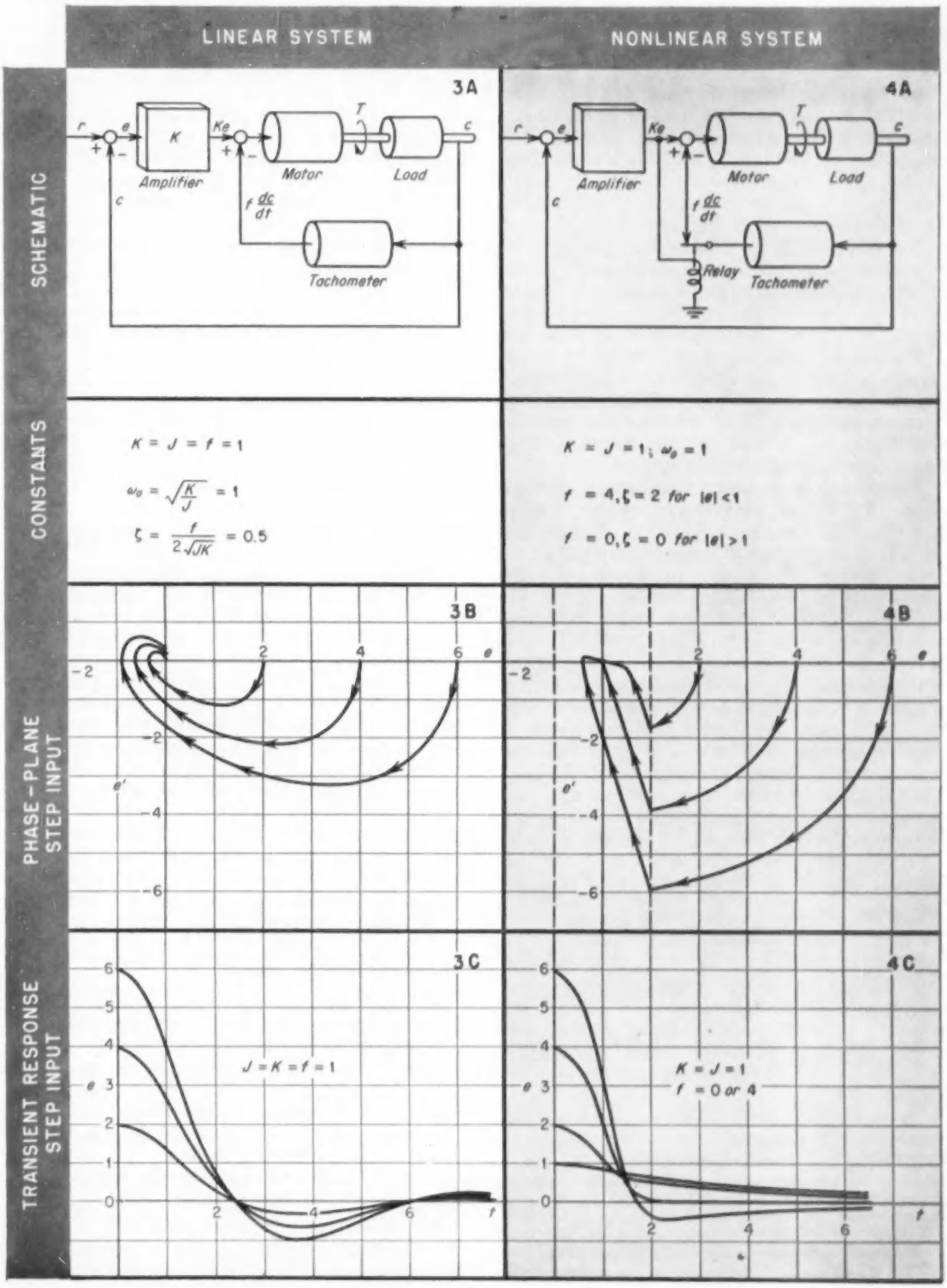
A gain control driven by the output shaft provides the required nonlinearity when its gain is inversely proportional to the cosine of the output position.

OPTIMIZING WITH NONLINEARITIES

Introduction of nonlinear elements also can improve control system performance without making the overall behavior linear. Batch processes use proportional plus reset controllers to obtain very accurate temperature regulation. Following large disturbances, such as those that occur on frequent start-up, the reset action produces a large overshoot. Since this overshoot is objectionable, it becomes desirable to switch out reset action whenever the error is very large. This is often done manually during start-up, but it can be automatic.

A similar problem occurs with positioning servos

NONLINEAR DAMPING IMPROVES RESPONSE



that use integral compensation. A circuit for limiting the action of an integrating network uses biased diodes across an integrating capacitor. Any integrated voltage exceeding the bias voltage is suppressed by conduction of the diode. A circuit of this type was illustrated in Part I of this series (Vol. 3, No. 2).

An ingenious scheme for reducing the "hiss" or "scratch" in hi-fi sound systems is based on the notion that these effects are most annoying when the general volume level is low. Since these effects appear at the high-frequency end of the sound spectrum they can be minimized by reducing the amplifier's bandwidth at low input signals.

For somewhat similar reasons it may be desirable to make a control system sluggish for small disturbances or noise, and yet not spoil its ability to respond rapidly to large disturbances. This can be done by varying the system gain, damping, or bandwidth as a function of error magnitude. Relays to change resistance values in gain-controlling or phase-correcting networks, or nonlinear resistors, are used. Figure 4 shows an error-actuated relay that changes the damping factor. Compare it with Figure 3. Both figures appear on the preceding page.

Figure 3A shows a basic second-order positioning servo. In this linear servo the tachometer develops the electrical equivalent of viscous friction and introduces damping at all times proportional to the load's velocity. The friction coefficient f is unity.

However, in a nonlinear second-order system like the one in Figure 4A, a relay is included. Whenever the error signal exceeds a predetermined value (unity) the relay operates to disconnect the output of the tachometer. Thus for small errors the system operates as a linear system with tachometer damping. In this case the friction coefficient equals 4, which means that the system is sluggish compared to the system in Figure 3A, where f equals 1.

But for large errors the relay in Figure 4A opens the tachometer circuit and the friction coefficient drops to zero. Thus for large disturbances the nonlinear system has no added damping. The load responds rapidly and reduces the error until the relay reconnects the tachometer. Then the system again becomes sluggish and returns to equilibrium at a slower rate.

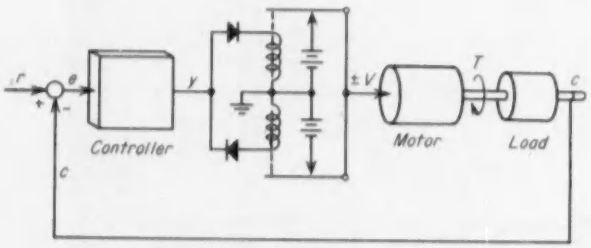


FIG. 5. This relay servomechanism programs, or optimizes, system response to disturbances provided that the controller and associated function generator are suitable for the given load conditions. In this way the system returns to zero error in minimum time without overshoot. Controller and function generator design are discussed in that part of the text dealing with various load conditions for this system.

The phase-plane plots of Figures 3B and 4B represent the behavior of the system. A phase-plane is constructed by simply plotting the error e, at a given time t, versus the error's time derivative e'. Selection of a sufficient number of e-e' points along the e-t and e'-t curves results in a complete phase-plane representation of the system. Trajectories for the linear system are similar spirals, their size depending on the magnitude of the step-change disturbance. The trajectories for the nonlinear system consist of circular arcs, followed by nearly straight lines when the error reaches unity and the relay introduces the high damping from the tachometer.

Figures 3C and 4C show the two systems' transient-response curves due to step-change disturbances. The linear system's curves are damped sinusoids whose ratio of overshoot to disturbance is independent of the step-change magnitude. However, the transient responses of the nonlinear system are quite different. Small initial errors are reduced slowly with no overshoot, while large initial errors reduce rapidly, overshoot, and then gradually decay to zero.

PROGRAMMED CONTROL SYSTEMS

Specially-designed relay servomechanisms reduce the error to zero without overshoot, in the minimum possible time consistent with inevitable saturations in the system, and regardless of the initial error magnitude. Such systems are known as "optimum" or "programmed" nonlinear servomechanisms. They have been the subject of much theoretical and laboratory investigation. The following discussion ties the theory of programmed nonlinear servos to some typical systems operations.

The essentially second-order system shown in Figure 5 will be used for illustration. Here either of two voltages, plus V or minus V, rotates the motor and drives the load into correspondence with the input signal, r. The controller programs relay operation so that the error is reduced to zero in a minimum time without overshoot.

Second-Order Systems

Figures 6 through 9 (spread on pages 82 and 83) show system operation with various types of loads.

The A sections of these figures show typical error responses to step-change disturbances for the various loads, the error's time rate of change (first derivative), and the time duration and direction of the motor torque required to bring the error to zero in minimum time without overshoot.

In the B sections a family of phase-plane representations for system operation is plotted. Each curve results from a particular magnitude of initial step-change disturbance. The phase planes carry a unique curve, AOB, representing conditions of e

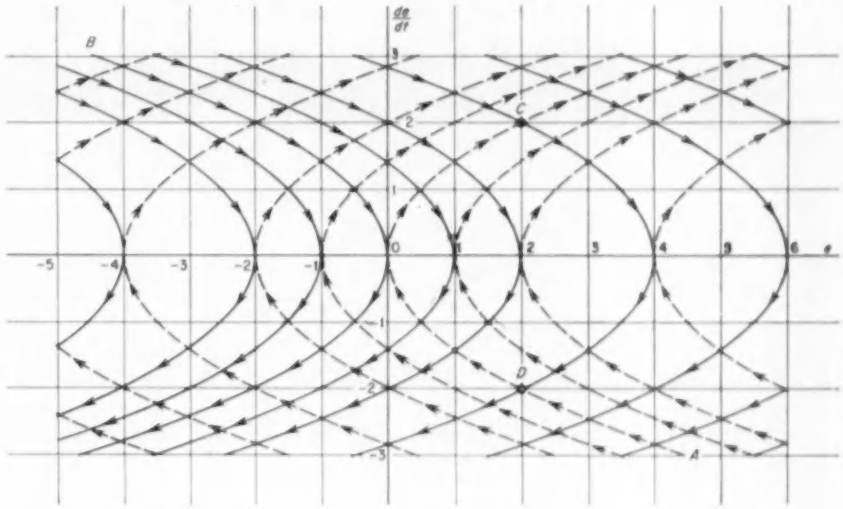


FIG. 10. Two curves pass through every point in the phase plane. But only one curve leads to the torque reversal, or switching, curve AOB, which is the shortest path to the origin (zero error). The function generator and controller select the appropriate sign of voltage, depending on unique values of error and its derivative. When the system reaches another set of values along the AOB curve the controller reverses the direction of applied torque and brings the system to zero along the AOB curve. For instance, an error starting at C needs a positive voltage; the system follows C4D, and at D the torque reverses.

and e' at which the torque should be reversed to reach zero error in minimum time without overshoot. Thus this torque reversal curve is known as the optimum switching curve. Logical functions must be built into the controller to sense the occurrence of the unique switching values of e and e'.

The C sections show that for some load conditions the response time is proportional to step-change magnitude, and in other cases the time is proportional to the square root of input magnitude.

Viscous Friction Only

If the torque T is instantaneously proportional to the applied voltage V (that is, the motor's electrical time constant equals zero) and if the load consists of viscous friction but no inertia (Figure 6), then the controller of Figure 5 need be merely an amplifier. The load rotates at constant speed whenever closed relay contacts (due to an error signal) apply voltage to the motor. And the motor stops immediately at zero error and consequent removal of voltage. No torque reversal is needed.

Inertia Only

The system of Figure 7 needs a more complicated controller. Suppose the torque reverses the instant that the voltage reverses, and that the load contains inertia but no friction. Since the motor voltage is either plus V or minus V, the equations of motion for the output shaft are:

$$c'' = +\frac{KV}{J} = +\frac{T_m}{J} \text{ for plus } V \qquad (1)$$

$$= -\frac{KV}{J} = -\frac{T_m}{J} \text{ for minus } V \qquad (2)$$

Here the primes denote time derivatives and T_m denotes maximum torque applied to the output shaft.

Since the error is defined as

$$e = r - c, \qquad (3)$$

then

$$e' = r' - c' \qquad (4)$$

and

$$e'' = r'' - c'' \qquad (5)$$

for step or ramp inputs $r'' = 0$, $c'' = -e''$, and the equations of motion can be written

$$e'' = -\frac{T_m}{J} \text{ for plus } V \qquad (6)$$

$$= +\frac{T_m}{J} \text{ for minus } V \qquad (7)$$

The solutions of these equations are easily obtained by direct integration, giving

$$e' = \pm\frac{T_m}{J}\, t + e'(0) \qquad (8)$$

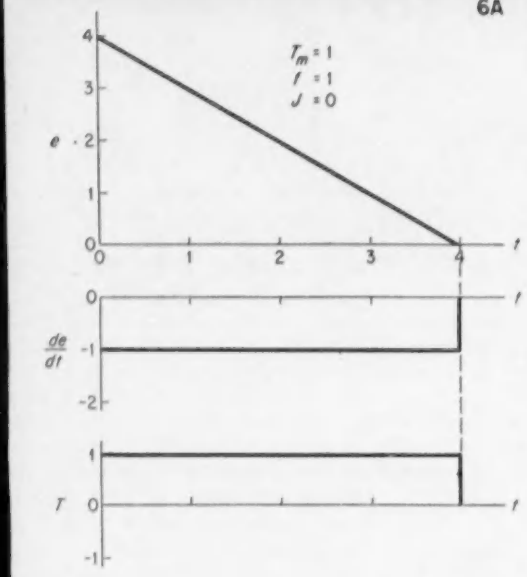
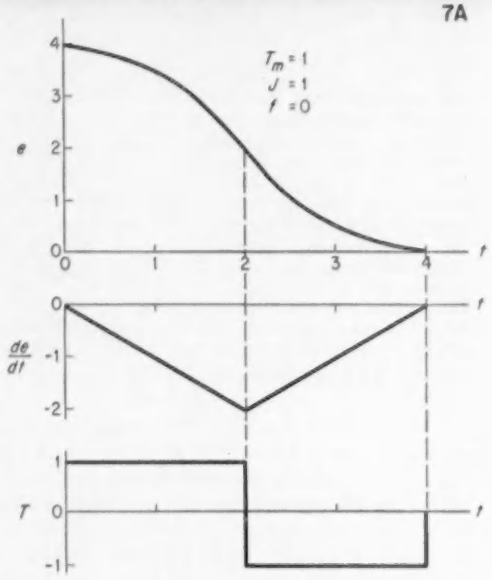
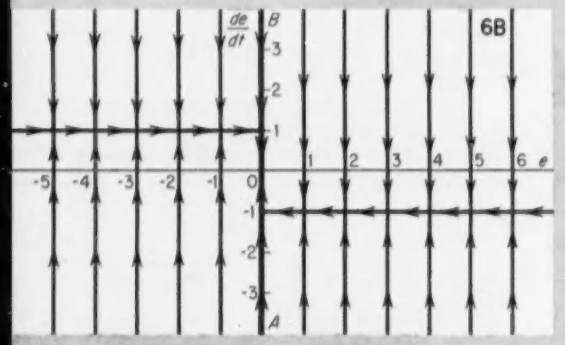
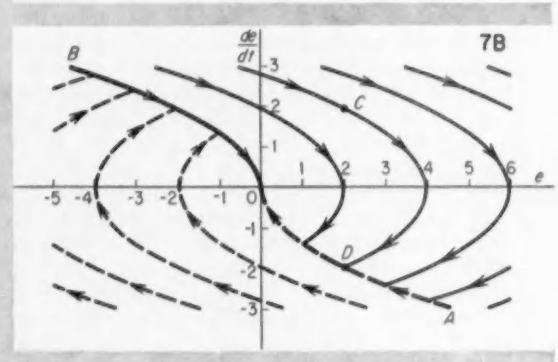
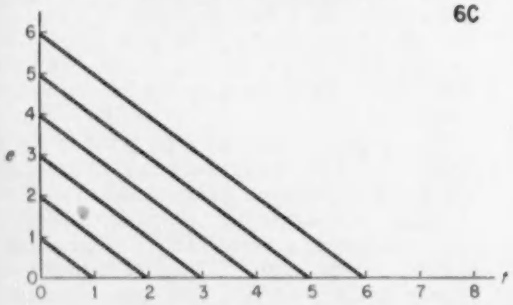
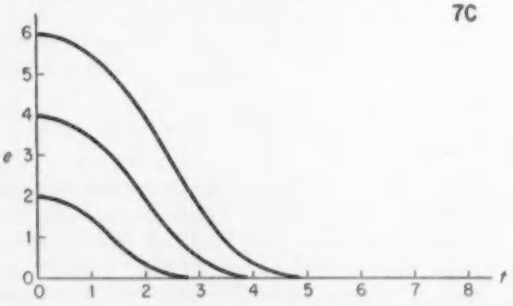
$$e = \pm\frac{T_m}{2J}\, t^2 + e'(0)\, t + e(0) \qquad (9)$$

with the signs chosen to fit Equations 6 or 7. If we eliminate t and plot e' as a function of e in a phase plane, the result, as shown in Figure 10, is two sets of parabolas, one for plus V (solid lines) and one for minus V (dashed lines). Arrows along these curves show the behavior of the system as t increases.

Two curves pass through every point in the phase plane. One of the curves heads away from the origin, and if system behavior followed this line it would never reach zero error. The other curve intersects the optimum switching curve AOB at some point, and at this point the system follows AOB to the origin. This is the shortest path. Suppose the system is initially at point C. The shortest path consists of the solid line C4D and the dashed curve DO.

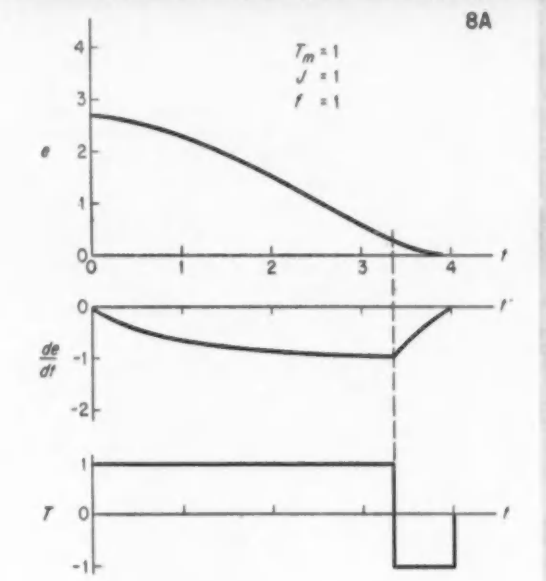
The controller's job is to examine e and e', choose the sign for V associated with a curve headed for the origin, close the appropriate relay, and apply torque in the proper direction. Thus the controller should pick plus V above and to the right of curve AOB,

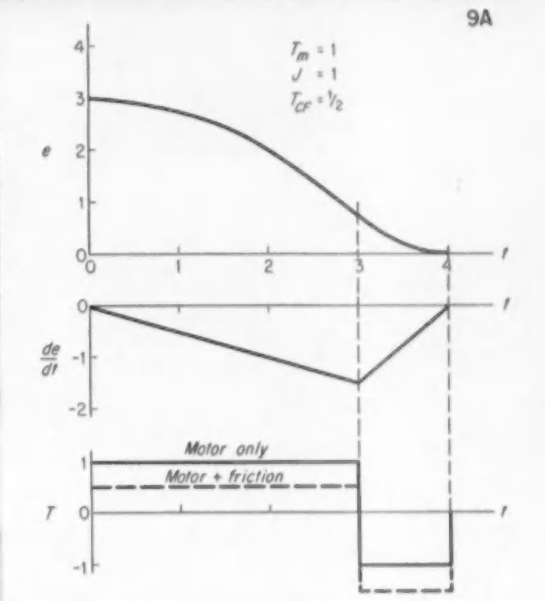
PROGRAMMED SERVO OPERATION

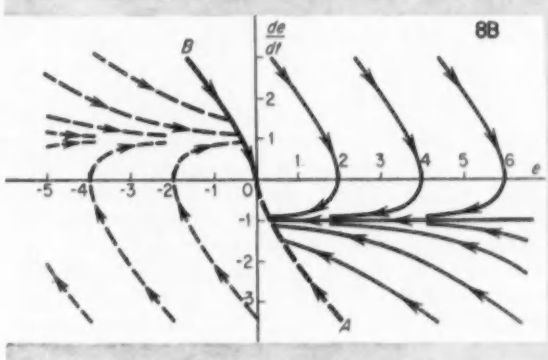
	VISCOUS FRICTION ONLY	INERTIA ONLY
SYSTEM RESPONSE TO A STEP CHANGE	6A 	7A 
PHASE PLANES	6B 	7B 
TRANSIENT RESPONSES	6C 	7C 
REMARKS	Response time is proportional to square root of step magnitude, but greater than for system with inertia only.	Response time is proportional to square root of step-change magnitude. No steady-state error for ramp inputs if error rate signal is used in the controller; but if output rate is used, the steady-state error (to maintain zero torque) is proportional to square root of input rate.

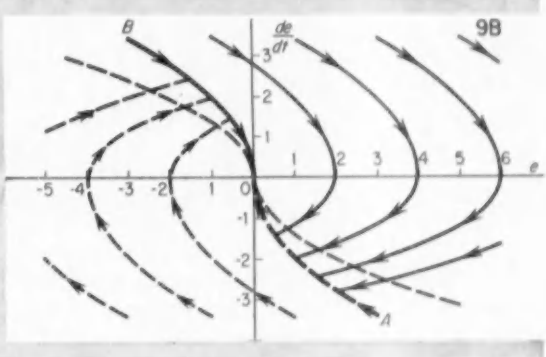
DEPENDS ON THE LOAD

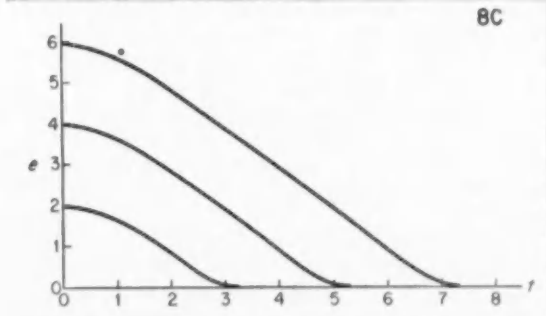
INERTIA & VISCOUS FRICTION	INERTIA & COULOMB FRICTION

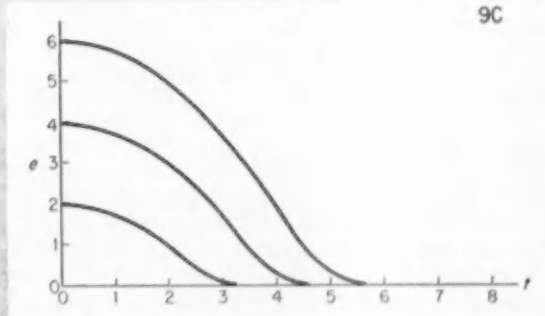












For small magnitude step-changes the response time is proportional to the square root of the magnitude; for large step-changes the response time is directly proportional to the magnitude. Switching curve for ramp inputs should change with input rate. Steady-state error for ramps is the same as for system with viscous friction only.

Response time is proportional to square root of step magnitude, but greater than for system with inertia only.

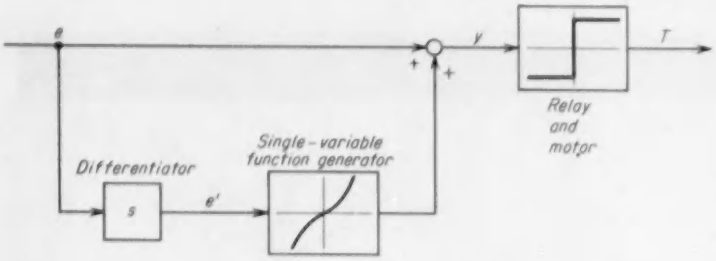


FIG. 11. This controller represents one way to mechanize Equation 11A and obtain the required torque reversal program for the system of Figure 7. Here the error is compared with the nonlinear function of the error's time derivative. When e is greater than e' the relay should apply plus V to the motor, and when it is negative the applied voltage should be minus.

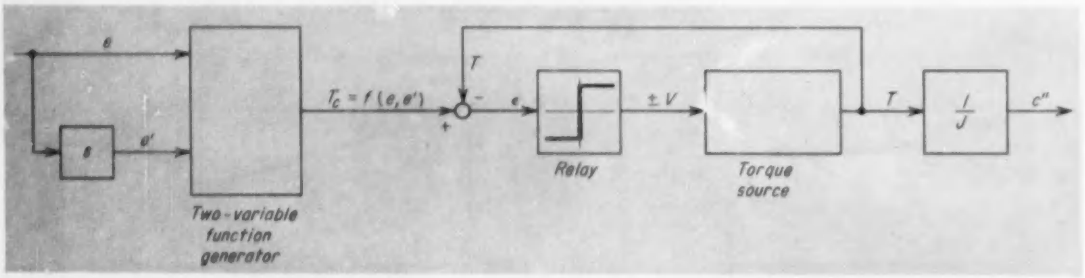


FIG. 13. The controller for a third-order servo requires a two-variable function generator. Here, the sign of the applied motor voltage depends on whether the computed torque T_c is greater or smaller than the torque T. This controller uses $T = Jc''$ instead of c'' and thus avoids two differentations of the error.

and minus V below and to the left. The resulting behavior for this system with inertia only is summarized in Figure 7B. It assumes correct action within the controller.

The equation for the switching curve AOB is

$$e = -\frac{J}{2T_m} e' |e| \tag{10}$$

or

$$e + \frac{J}{2T_m} e' |e| = 0 \tag{11}$$

Now, if

$$y = e + \frac{J}{2T_m} e' |e'| \tag{11A}$$

the controller should select plus V when y is positive, and minus V when y is negative. The controller in Figure 5 then mechanizes Equation 11A, and can be constructed along the lines suggested in Figure 11. The function generator must produce a parabolic (nonlinear) relationship because of the product of e' and the absolute magnitude of e'.

Inertia and Friction

These general principles apply if the load has friction as well as inertia. Friction torque reduces the torque available for acceleration of the output shaft, but helps during deceleration. Reversal of V must occur later than in the system with inertia only, and this requires that the switching curve move closer to the vertical axis of the phase plane. The same sort of controller as shown in Figure 11 can be used to set up the optimum switching conditions required by a different switching program. The AOB curve now generated by the function generator must, of course, be different also. System behavior with viscous friction and inertia, and coulomb friction and inertia, are shown in Figures 8 and 9.

Third-Order Systems

Suppose the torque developed by the motor in Figure 5 is not instantaneously proportional to the applied voltage. Now the system's differential equations of motion are third-order and programmed operation requires a more complicated controller.

Consider the system of Figure 12A. Here the error acceleration e'' is proportional to a torque that varies linearly between two limits. This might represent the developed torque of a boat or airplane rudder driven between two stops by a constant speed motor. However, the error acceleration of Figure 12B varies exponentially with time, the result, for instance, of field inductance in a dc motor.

Third-order system trajectories can be plotted in three-dimensional space having, for example, e, e', and e'' as coordinates. The switching curve of the simpler second-order system now becomes a switching surface.

The vertical dashed lines of Figure 12A and 12B indicate that V must be reversed twice for optimum system operation; that is, the error must be brought to zero in minimum time with zero overshoot.

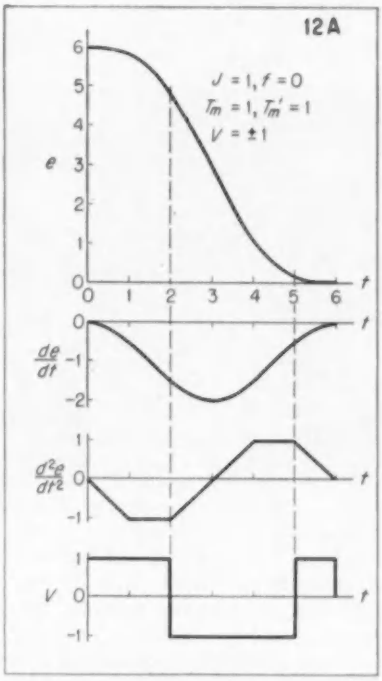
Switching operations occur at unique combinations of e, e', and e''. By analogy with Equation 10 the switching surface can be expressed by:

$$e = g(e', e'') \tag{12}$$

$$e' = h(e, e'') \tag{13}$$

or

$$e'' = f(e, e') \tag{14}$$



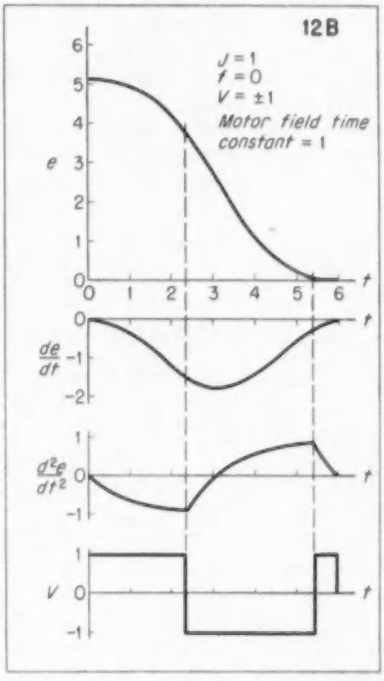


FIG. 12. When a finite time is required to develop maximum torque the system of Figure 5 becomes third-order. Now the system needs two reversals of voltage to reach zero error in minimum time with zero overshoot. Voltage reversals occur at the unique combinations of e, e′ and e″ as indicated by the vertical dashed lines. The controller selects plus or minus V depending on the combinations of the three variables, and programs the system to zero error under optimum conditions. In Figure 12A error acceleration is proportional to a linear torque, as from a rudder driven by a constant speed motor. In Figure 12B the error acceleration varies exponentially, as from the effect of the motor's electrical time constant.

A SYSTEM'S PLOT . . . .
. . . . AND ITS PHASE SPACE DIAGRAM

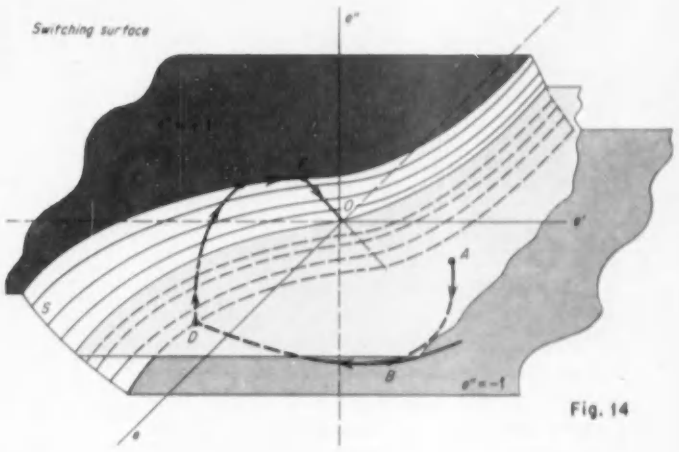


Fig. 14

Figure 13 shows a way, based on Equation 14, of constructing the controller. The function generator's output is called a computed torque, T_c. This is compared with the actual torque T, and any difference between T and T_c actuates the relay in the correct direction to apply either plus V or minus V. This controller uses $C = Je''$ instead of e'', and thereby avoids two differentiations of the error. This arrangement introduces no difficulties with step or ramp inputs if the load contains inertia only.

Contour lines of the system of Figure 12A are plotted in Figure 14. Suppose the initial error starts at point A with T equals zero. There will be a preliminary trajectory AB along which the torque increases as fast as possible. At B the torque reaches its maximum value and T equals T_c. The trajectory continues along the $T_c = e'' = -1$ plane to D, and at this point the relay reverses and torque decreases. At F the torque reaches its maximum negative value and immediately starts back to zero error.

In practice, inputs other than steps can be expected. Calculation of the system response to other inputs such as sinusoidal or random disturbances is difficult. Analog computers with appropriate nonlinear function generators have therefore been used.

In order to apply the theory rigorously to a second-order servomechanism, one-variable function generators (which are readily available) are necessary. In higher-order systems, multi-variable function generators are necessary.

Multi-variable function generators are less common than single-variable, and this fact has impeded rigorous investigation of real systems. The theory does serve, however, as a basis for design of practical systems with very nearly optimum response, using simplified equipment whose performance approximates the ideal.

Visualizing Resolver Circuits

Computing problems involving resolution into components, conversion from rectangular to polar coordinates, or transformation of coordinates, are often solved with resolver systems. If the equations solved by these systems are complex, it's possible to get lost in a mass of trigonometric relationships before finally emerging with the computer. An easier approach is to sketch a vector diagram of the problem, and to directly design the resolver computer by inspecting this diagram. The trigonometric equations and the space-geometry figure are equivalent, but the diagram makes it easier to visualize the transformation problems. Learn the technique by following the examples herein.

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Electronics Div., American Machine & Foundry Co.

Typical plane and spherical trigonometry problems are encountered in navigation, gunfire control, missile guidance, bombing, and machine-tool contouring. These problems can be solved with electromechanical analog computers using resolver networks. For example, the trigonometric problems solved electronically in *Tracing a Contouring System From Idea to Application*, page 65, can also be solved electromechanically with resolvers. In carefully designed systems, accuracies are within 0.1 per cent in magnitude and 0.25 deg in angle, with minimum angular errors of about 1 min.

A resolver consists basically of two rotor coils with mutually perpendicular electromagnetic fields, and

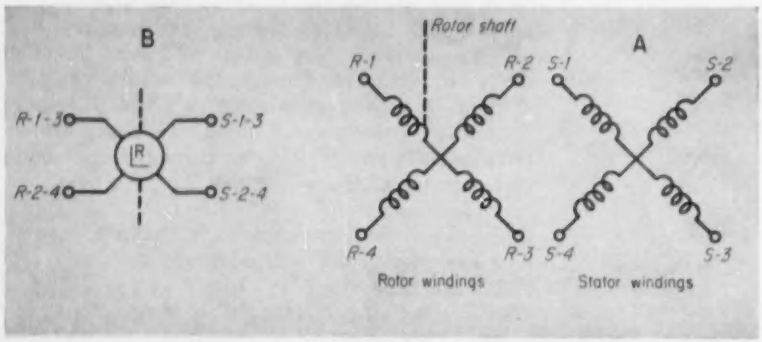


FIG. 1. A. Schematic of resolver winding configuration. B. Symbolic representation of a resolver.

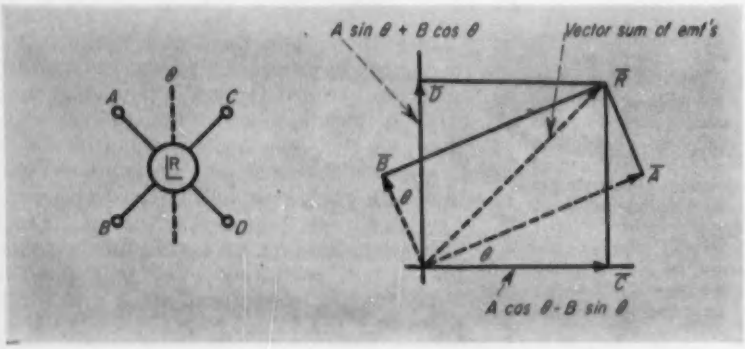


FIG. 2. Rotating coordinates with a resolver.

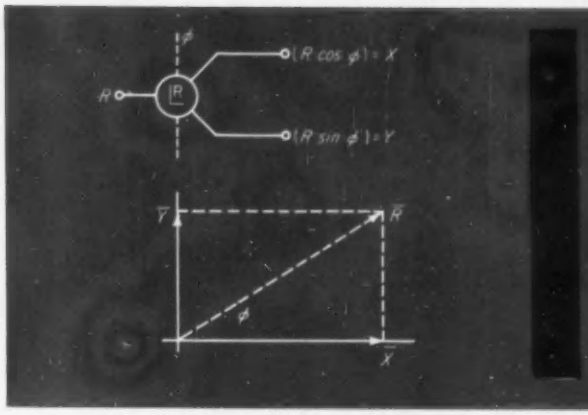


FIG. 3. Transforming from polar to rectangular coordinates with a resolver.

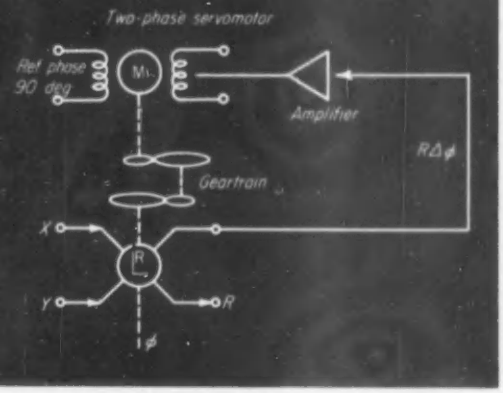


FIG. 4. Transforming from rectangular to polar coordinates with a resolver.

two stator coils with mutually perpendicular electromagnetic fields. The rotor coils can be positioned at any angle to the stator coils, Figure 1A. A resolver can be represented symbolically by the diagram of Figure 1B. The voltage transformation ratio between a rotor and stator winding when they are parallel is held to a stated, close tolerance by the manufacturer. It is often unity. When the rotor and stator windings are not parallel, then the voltage transformation ratio is proportional to the cosine of the angle between the rotor and stator. In Figure 1A, if *R-1,R-3* is at an angle θ to *S-1,S-3*, then 1 volt across *R-1,R-3* gives *K* cos θ volts across *S-1,S-3*. In this discussion, the transformation ratio, *K*, is assumed unity.

BASIC RELATIONSHIPS

If *A* volts are impressed across *R-1,R-3*, and *B* volts are impressed across *R-2,R-4*, and *R-1,R-3* is at angle θ with *S1,S-3*, these stator voltages are generated:

across *S-1,S-3*	A cos θ — B sin θ
across *S-2,S-4*	A sin θ — B cos θ

These equations are derived by considering the effects of voltages A and *B* acting through the angle θ. In Figure 2, a vector diagram of these voltages, the angles are the space relationships between magnetic fields and the line lengths are voltage magnitudes.

But it is possible to achieve the same results without considering these formulas by simply stating that voltages *A* and *B* are transformed to voltages *C* and *D* through the angle θ. This transformation is easily understood when it is realized that *A* and *B* combine to form the magnetic vector *R*, which in turn induces voltages *C* and *D* in windings *S-1,S-3* and *S-2,S-4*. A visual inspection of this simple vector diagram is all that is required to convey a complete idea of what takes place in this transformation.

To transform a vector in the polar form *R*, ϕ to its rectangular coordinates, it is only necessary to impress *R* on one of the resolver windings (say *R-1,R-3*) and move the rotor until *R-1,R-3* forms the angle ϕ with *S-1,S-3*. This is shown in Figure 3. The other rotor winding is not used. The terms *R* cos ϕ and R sin ϕ are simply mathematical statements of the completed parallelogram of vectors.

To transform from rectangular to polar coordinates, it is necessary to drive the resolver rotor with a servomechanism. If the voltages X and Y in Figure 3 are impressed on the stator windings of a resolver, and the rotor is positioned so that one of its windings makes an angle ϕ with X, then this winding is parallel to the resultant magnetic vector and has induced in it the voltage *R*. The other rotor winding, at right angles to the resultant magnetic field, has no voltage induced in it. If the angle differs from ϕ by an angle $\Delta\phi$, then the voltage in one winding is still close to *R*, and in the other winding is $R\,\Delta\,\phi$. The phase of the null voltage reverses at $\Delta\phi$ equals 0. The servo aligns the rotor so that one of its windings is parallel to the resultant magnetic vector.

A typical circuit for rectangular-to-polar transformation is shown in Figure 4. The error signal is amplified and the motor drives the rotor in the proper direction to minimize $R\,\Delta\,\phi$. Even though there are two voltage-null positions of the rotor (180 deg apart), only one of these is a stable null.

By combining these three functions:

- rotating rectangular coordinates
- transforming from polar to rectangular coordinates (resolving into components)
- transforming from rectangular to polar coordinates (finding resultant) with addition and subtraction, it is possible to solve most plane and spherical trigonometry problems. And by becoming familiar with the resolver connections that will yield these functions, it is possible to design a resolver network by following a step-by-step procedure through a vector diagram of the problem without ever referring to

or using the specific trigonometric relationships. Of course, while this procedure yields the answer to the trigonometric problem, it does not solve the electrical difficulties associated with cascading resolvers. The problems of loading and noise must be handled after the basic circuit configuration is selected.

The solution of two-dimensional problems by this technique, as shown in the first of the following examples, is simple and needs no further comment. But three-dimensional vector diagrams are more complex. Three-dimensional problems are solved by rotating two or three mutually perpendicular vectors representing a space vector into two or three different mutually perpendicular vectors representing the same space vector. It is necessary to carefully sketch an oblique or isometric view of the three-dimensional figure. If the problem is particularly complex, a scale model of the problem, using wire and plywood, often helps in visualizing these space vectors.

In the following three-dimensional problems, vector lengths are often not shown on the diagram. These vectors all originate at the center of the spherical coordinate system. In all the examples, an original range vector is expressed in its rectangular coordinates. Then, after a number of transformations, the end result is the original range vector (with the required information obtained in the process). This is often used in checking the system. Some study must be given to the three-dimensional figures before they become completely familiar.

HOW TO USE THIS TECHNIQUE

EXAMPLE 1

PROBLEM—In the AN/APQ-T2A Ultrasonic Bomber/Navigator Training Equipment used by the Air Force, there is a plane map, Figure 5A, on which the longitude meridians are straight lines radiating from some point that may or may not be on the map. A point P is defined by x and y coordinates from O, the map center. This indicates a mixed arrangement of rectangular and polar coordinates. Knowing the map distance from O to N, the north pole, and the angle β between ON and the Y axis, find the true bearing of the Y axis at P (i.e., the angle α).

SOLUTION—Using a resolver circuit, rotate vectors x and y through angle β to form vectors OQ and PQ. To help explain this first example, this coordinate rotation is shown in detail in Figure 5B. Subtract OQ from ON, giving QN. Using the new values PQ and QN, transform from rectangular to polar coordinates to obtain NP and the angle α plus β, Figure 5C. Subtract β from α plus β to give α, the desired angle. The resolver-instrumented system is shown in Figure 5D. The mechanical additions and subtractions can be performed with mechanical differentials, and the electrical additions by series-voltage addition or resistor addition.

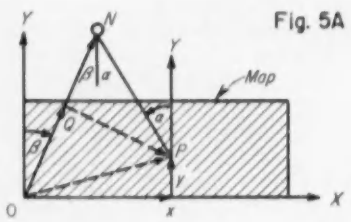


Fig. 5A

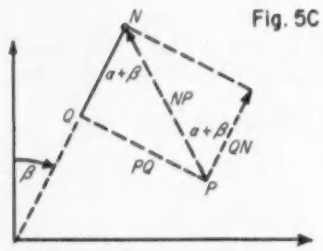


Fig. 5C

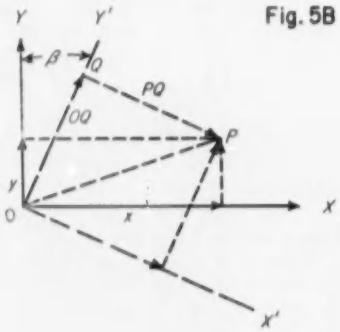


Fig. 5B

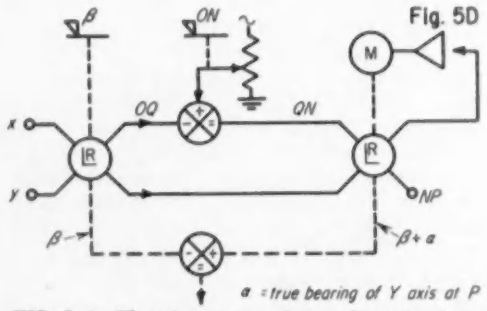


Fig. 5D

FIG. 5. A. The trigonometry of a two-dimensional plane map problem. B. One step in the solution: rotation of coordinates. C. Transforming rectangular coordinate vectors into a polar vector and an angle. D. The resolver computer.

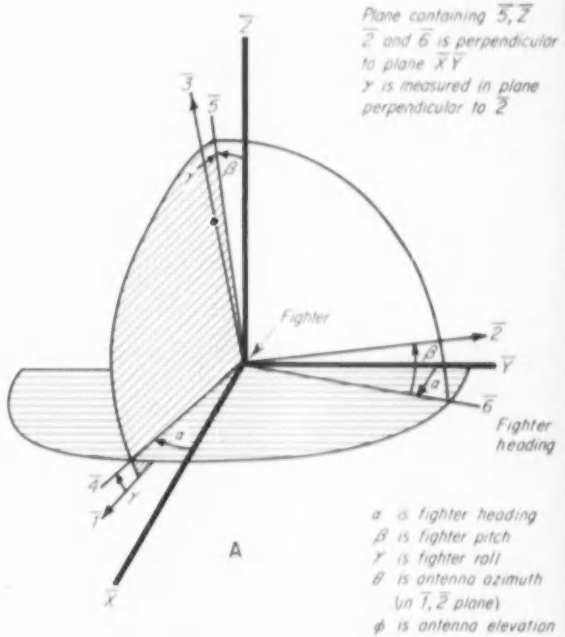
EXAMPLE 2

PROBLEM—In the AN/APG-T1A Radar Gunnery Trainer used by the Air Force, problems to be solved relate to gating "on" the synthesized radar signal to the radar indicator. The X, Y, and Z space coordinates between a synthesized fighter and bomber are given, as well as the pitch, roll and Y-heading of the fighter. (See Figure 6A for symbol definitions.) Find the azimuth and elevation angles (with respect to the fighter coordinate axis), at which the fighter radar antenna is pointing at the bomber. When the antenna angles coincide, the synthesized radar signal is gated "on".

SOLUTION—Use a resolver system to transform the space coordinates so that the $\bar{X}$, $\bar{Y}$, and $\bar{Z}$ vectors from fighter to bomber are expressed as $\bar{1}$, $\bar{2}$, and $\bar{3}$ vectors. These latter are perpendicular to each other (as are $\bar{X}$, $\bar{Y}$, and $\bar{Z}$) but form the coordinate system of the fighter. Essentially the space coordinates are corrected for the heading, pitch, and roll of the fighter to form the fighter coordinate system. Since the radar antenna is physically attached to the fighter, this is a necessary first step. Then the required antenna azimuth and elevation angles are measured in the planes formed by $\bar{1}$ and $\bar{2}$, and $\bar{7}$ and $\bar{3}$, respectively, Figure 6B. The steps to be taken are as follows:

a. Rotate coordinates of vectors $\bar{X}$ and $\bar{Y}$ through the fighter heading angle α to form vectors $\bar{4}$ and $\bar{6}$ (still in XY plane).
b. Rotate coordinates of vectors $\bar{6}$ and $\bar{Z}$ through pitch angle β to form vectors $\bar{2}$ and $\bar{5}$.
c. Rotate coordinates of vectors $\bar{5}$ and $\bar{4}$ through roll angle γ to form vectors $\bar{1}$ and $\bar{3}$.
d. Transform the rectangular coordinate vectors $\bar{1}$ and $\bar{2}$ to the polar vector $\bar{7}$ and the angle θ. This gives the antenna azimuth.
e. Transform the rectangular coordinate vectors $\bar{3}$ and $\bar{7}$ to the original vector (between fighter and bomber) and the angle ϕ. This gives the antenna elevation.

This is instrumented as shown in Figure 6C.



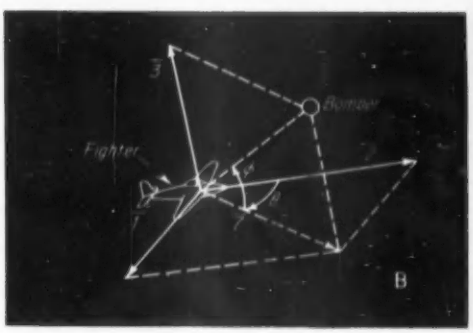
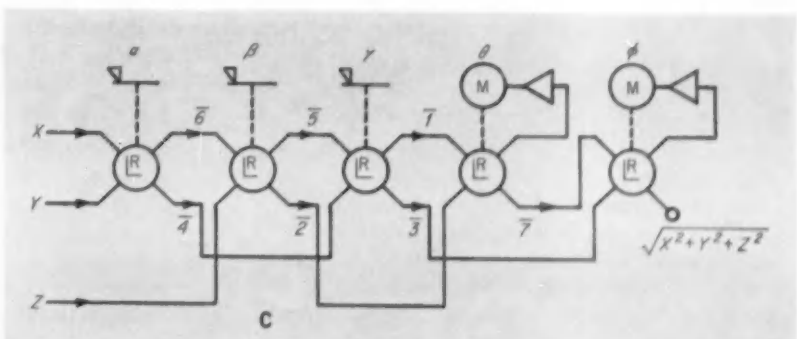


FIG. 6. A. The trigonometry of a three-dimensional problem in air-to-air gunnery training. B. Azimuth and elevation of radar antenna related to fighter coordinate system. C. The resolver computer.



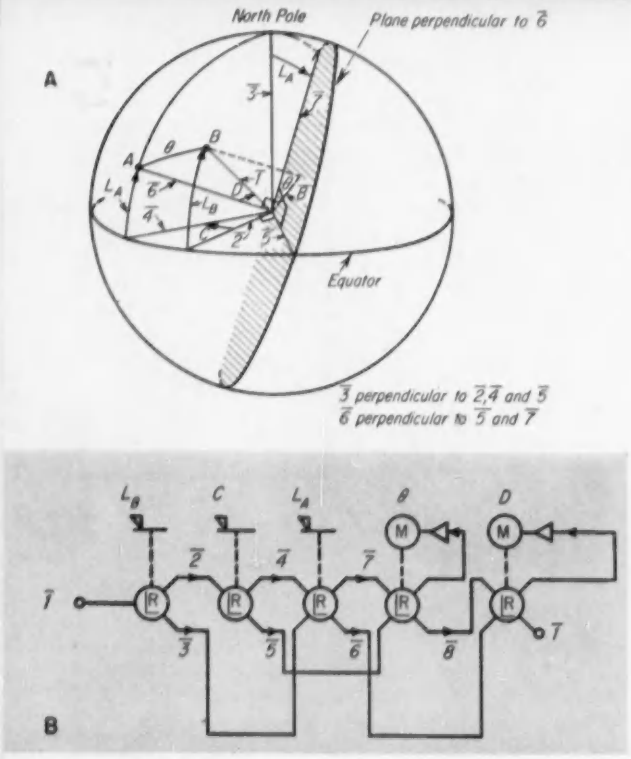


FIG. 7. A. Trigonometry of three-dimensional navigational problem. B. Resolver computer.

EXAMPLE 3

PROBLEM—Given the latitude and longitude of an aircraft's position, and that of its destination, what is the true bearing of its desired ground track to fly a great circle to its destination? What is the distance to its destination?

SOLUTION—Use a resolver system to effect the required transformations in solving for the angle θ (bearing of desired ground track), and the angle D (distance to destination). In Figure 7A, A is the aircraft and B is its destination. The plane shown shaded is perpendicular to vector $\bar{6}$ (vector from origin through A), and L_A and L_B are the latitudes of A and B, and C the longitude difference.

The steps to be taken are as follows:

a. Transform polar vector $\bar{1}$ and angle L_B to rectangular coordinate vectors $\bar{2}$ and $\bar{3}$.

b. Transform polar vector $\bar{2}$ and angle C to rectangular coordinate vectors $\bar{4}$ and $\bar{5}$. Notice that this means $\bar{5}$ is perpendicular to $\bar{3}$ and to $\bar{6}$ ($\bar{5}$ lies in perpendicular plane).

c. Rotate coordinates of vectors $\bar{3}$ and $\bar{4}$ through angle L_A to form vectors $\bar{6}$ and $\bar{7}$. Then $\bar{7}$ falls in perpendicular plane. Notice that the plane formed by the vectors $\bar{4}$, $\bar{6}$, $\bar{3}$, and $\bar{7}$ and the plane formed by the vectors $\bar{1}$ and $\bar{6}$ intersect at the angle θ. This leads to the next step.

d. To find the projection of vectors $\bar{1}$ and $\bar{6}$ on the perpendicular plane, transform the rectangular coordinate vectors $\bar{7}$ and $\bar{5}$ into the polar vector $\bar{8}$ and the angle θ. This is the bearing of the desired ground track.

e. Finally transform the rectangular coordinate vectors $\bar{8}$ and $\bar{6}$ into polar vector $\bar{1}$ (the original vector) and the angle D. This angle represents the distance to the destination.

Note that the vector $\bar{1}$ is finally resolved into three mutually perpendicular vectors, one of which is $\bar{6}$. The others are $\bar{7}$ and $\bar{5}$. The computer to accomplish this is shown in Figure 7B.

EXAMPLE 4

PROBLEM—In a special purpose analog computer, a new set of transformed latitudes and longitudes must be derived. The earth latitude and longitude of any point P are given. A great circle, called the "map equator", intersects the earth equator at longitude α, and at a slant angle β. Find the "map latitude" and "map longitude" of point P, where the "map zero degree meridian" passes through the intersection of the "map equator" and the earth equator. Terms are shown in Figure 8A.

SOLUTION—Referring to Figure 8B, the latitude and longitude of point P is completely defined by vector $\bar{1}$ whether "map" or earth latitudes and longitudes are used. Using earth coordinates, vectors $\bar{2}$ and $\bar{3}$ can be found. These also completely define P. Then by using the given angles, three new mutually perpendicular vectors, $\bar{4}$, $\bar{6}$, and $\bar{7}$, can be found. By a rectangular to polar conversion of vectors $\bar{4}$ and $\bar{7}$, vector $\bar{8}$ and angle L_M can be determined, where L_M is the "map longitude". Finally, by another rectangular to polar conversion of $\bar{8}$ and $\bar{6}$, the "map latitude" or λ_M is determined.

The steps to be taken are as follows:

a. Transform polar vector $\bar{1}$ and angle λ_T to rectangular coordinate vectors $\bar{2}$ and $\bar{3}$. Where λ_T is the earth latitude of point P.

b. Transform polar vector $\bar{2}$ and angle $(\alpha - L_T)$ to rectangular coordinate vectors $\bar{4}$ and $\bar{5}$. Where L_T is the earth longitude of point P.

c. Rotate coordinates of vectors $\bar{3}$ and $\bar{5}$ through angle β to form vectors $\bar{6}$ and $\bar{7}$.

d. Transform rectangular coordinate vectors $\bar{4}$ and $\bar{7}$ to polar coordinate vector $\bar{8}$ and angle L_M. Where L_M is the desired "map longitude".

e. Transform rectangular coordinate vectors $\bar{6}$ and $\bar{8}$ to polar coordinate vector $\bar{1}$ (the original vector) and angle λ_M. Where λ_M is the desired "map latitude".

This can be instrumented as shown in Figure 8C.

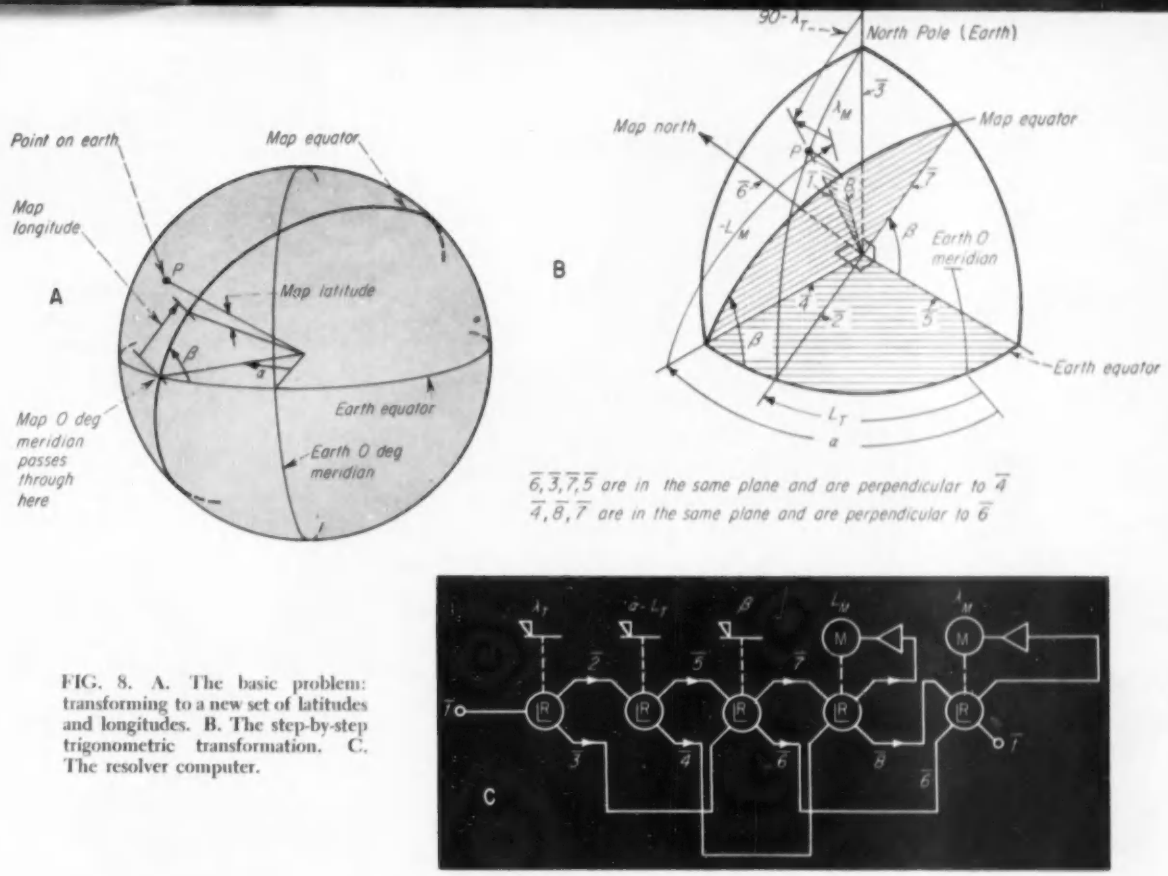


FIG. 8. A. The basic problem: transforming to a new set of latitudes and longitudes. B. The step-by-step trigonometric transformation. C. The resolver computer.

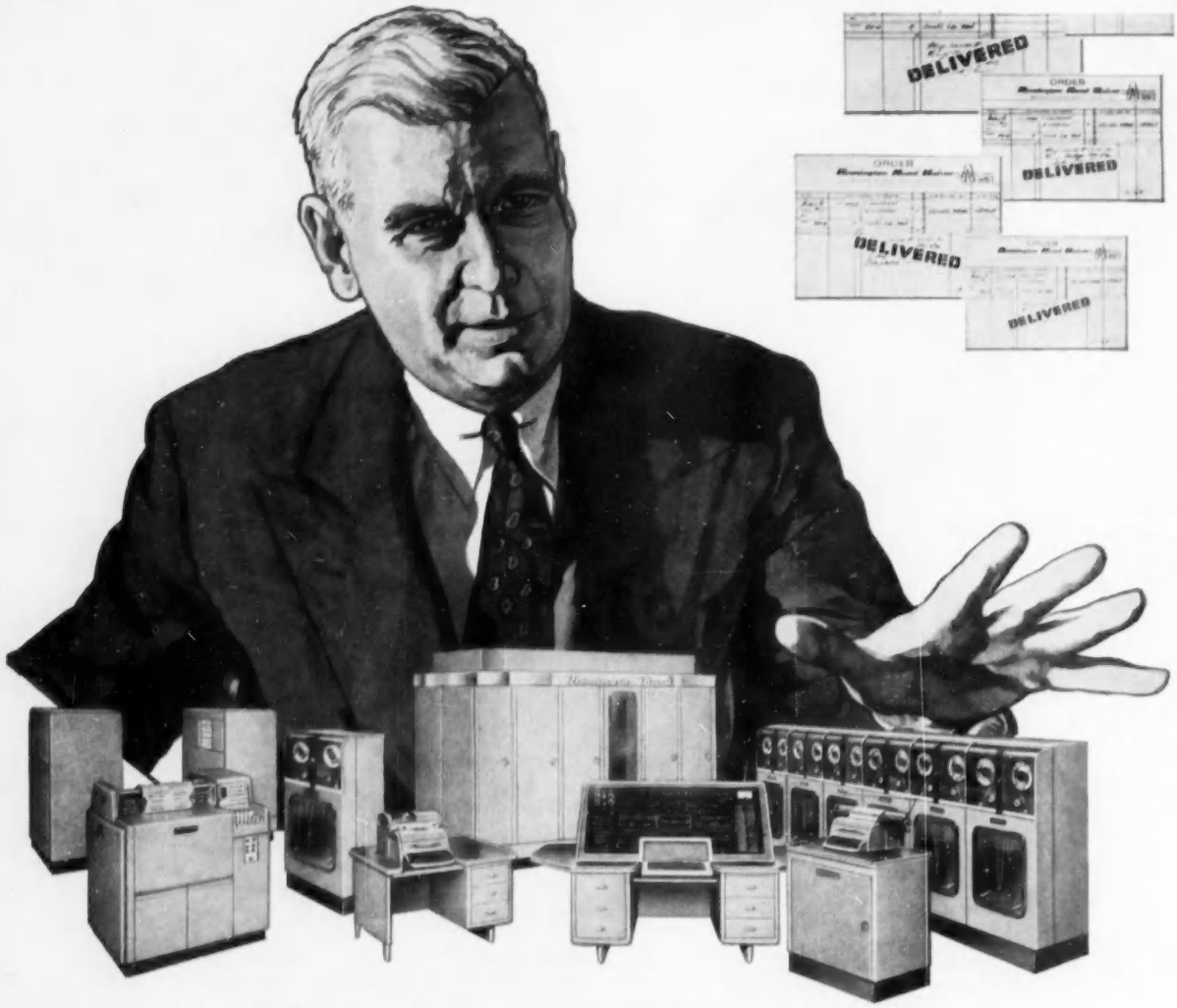
PROBLEMS OF CASCADED RESOLVER SYSTEMS

As mentioned previously, the computers shown here are simplified in that they include only those devices necessary to perform the trigonometric transformations. Actually, most resolver windings have low impedances, and it is necessary to isolate one resolver winding from another by means of a buffer amplifier that has a high input impedance and a low output impedance. Serious loading errors appear unless this is done. Buffer amplifiers must have accurately controlled gain and carrier phase-shift characteristics and must not require frequent adjustment. These amplifiers are available commercially.

Phase shift of the carrier voltages can cause serious problems, especially in rectangular to polar transformations. If the two voltages feeding a resolver used for this type of transformation are not in phase, a quadrature component is generated. This prevents the "null" winding of the resolver from actually having a complete null position. System phase shifts must be carefully adjusted to minimize this problem.

Since buffer amplifiers are used to compensate phase shifts (and individual winding transformation ratios), the phase-frequency characteristic of these amplifiers is not constant. This often results in a higher gain for the noise frequencies than for the 60 or 400 cps carrier. Also, the resolver itself may show a similar increase in transformation ratio for some noise frequencies. Cascading resolvers accentuates this problem, and careful design is required to ensure that a large amount of noise does not mask the "null" position of the last few cascaded resolvers.

In the case of rectangular to polar transformation, null sensitivity of the servo must also be considered. For example, in Figure 7A, the θ servo null sensitivity (error in volts for a given angular error in θ) is directly proportional to the vector $\overline{8}$. When this vector length decreases, the θ servo sensitivity decreases and the θ solution is less accurate. There are three approaches to this problem. The first neglects this decrease in sensitivity. This approach can be used when the value of the "range" vector $\overline{8}$ does not change enough to affect the desired accuracy of the θ solution. The second approach uses the value of the range vector to modify the gain of the θ servo, so that automatic gain control is obtained. This type of AGC is used in some of the equipment partially described here. Satisfactory performance over a range vector change of 1,000 to 1 has been maintained. The third approach uses a range computing circuit, the reciprocal of range multiplying the servo error. Thus, error is independent of range as long as the reciprocal computation is accurate.



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How Computers Do Arithmetic

Previous articles in this series discussed the logical problems that commonly arise in computer design as well as circuits that can solve them. Mr. Blankenbaker shows how the familiar problems of addition and subtraction, multiplication and division are reduced to sequences of logical problems. Thus, computer units that can do arithmetic become practical.

JOHN BLANKENBAKER
Hughes Aircraft Co.

In a digital computer, the arithmetic unit does the ordinary arithmetic. The control unit orders operations and supplies timing and sequence signals to the arithmetic unit. These signals synchronize the arithmetic unit with other units and control its internal sequence of operations. The computer's memory supplies the operands and receives the computed results.

The form of an arithmetic unit depends largely on the major system decisions, such as whether to use serial or parallel operation, or binary or decimal number representation. The design varies also with the physical elements and circuits used in the mechanization.

In all cases, the steps to problem solution must be reduced to operations that the physical circuit elements can perform. For example, multiplication may be resolved into additions and shifts. But the addition problem itself must then be analyzed to find how physical circuits with logical characteristics may generate a sum. This article shall show how the arithmetic functions may be resolved into step-by-step decisions that logic circuits can perform.

The computer may add the digits of two numbers all at once, as in a "parallel" machine, or sequentially, as in a "series" machine. The computer may operate entirely in the binary number system, or it may use a binary coded decimal system. Thus it is surprising that many of the logical simplifications of the mathematical functions apply in common from arithmetic unit to arithmetic unit.

The physical elements used to construct arithmetic units are the "gates" and "one-bit short-time storage elements" (particularly the "flip-flops") described in the two latest articles in this series. The logical model of the storage element is a box that represents a "delay", and has one input and two outputs. One output equals the input during the preceding time interval (between computer synchronizing pulses). The second output is the binary complement of the first.

Logically, a gate has no time delay. An AND gate has a binary "1" output only if all its inputs are 1's. An OR gate has a 1 output if any input is 1.

From a given set of states of the flip-flop signals the machine must advance to another set of states which represents a step in the solution. The choice of flip-flops to use, the way their states will be represented and sequenced, and the determination of the gating networks constitute the principal task in designing an arithmetic unit.

In some cases flip-flops are grouped together, physically and logically, for a specific purpose. In such cases they are often called "counters" and "registers". The significance is usually implied that counters have a predetermined action sequence and that registers store some number that must be represented. The register could be one of the arithmetic registers and the number it stores could be an operand. Storing an operand in flip-flops is expensive. In serial systems, which do not require this much information to be displayed at one time, circulating registers are used as an alternative. In a circulating register a few bits are held at one time in flip-flops, and the rest are stored in some form of delay line cheaper than flip-flops. The name circulating comes from the fact that the information will circulate through the display flip-flops and the delay line in a continuous sequence until changed. Thus the states of any one of the flip-flops represent a time sequence of the information stored in the register.

REGISTERS

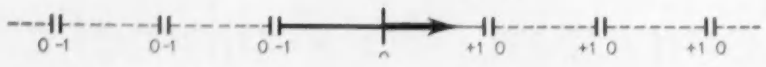
The register is the most obvious feature of arithmetic units. There are usually three used to store operands, partial results, and completed results. With three registers, multiplication and division can be done without referring to the memory. The names "multiplicand", "multiplier", and "accumulator" are often used for the registers. Sums are formed in the accumulator.

A given register can have only a finite number of combinations, i.e., a fixed capacity. The numbers that these combinations represent depend on where the decimal point (or binary point) is considered to lie. As will be seen in multiplication and division, it is somewhat more convenient to consider all numbers less than one in magnitude.

ADDITION AND SUBTRACTION

In a ten-digit decimal register which has an associated sign and is used to

represent fraction numbers, any ten-digit number in the range from $-(1-10^{-10})$ to $+(1-10^{-10})$ may be represented. Graphically it could be represented as



where the vector represents the particular contents of the register.

A positive number is represented by a vector from the origin to the right, a negative number to the left. Adding two vectors is equal to numerical addition, subtracting two vectors is equal to the subtraction process. The rules governing the adding or subtracting of a second number from a number in the register may be expressed thus: if the second number is positive and addition is desired or if it is negative and subtraction is desired, then the second number is added. If the second number is negative and addition is desired or if it is positive and subtraction is desired, then the second number is subtracted from the first. These rules may also be stated this way: the second number is always treated as positive and its sign is combined with the operational sign of add or subtract.

Thus, the addition of two positive numbers that are each at least one-half the size of the maximum register representation will produce a result that is to the right of the plus 1 point. This produces no difficulty; the graphic picture of the register extends to the right or left for as many cycles as it is cared to extend it. However, these cycles are indistinguishable from the primary positive cycle. The loss of information by this process is called overflow. Because the lost information is a known magnitude, in this case equal to 1, it can be recovered by detection and supply of overflow program-wise or by alarm to the operator.

The rules of binary addition and subtraction are very simple. There are only two values for each digit; two digits combined in an operation result in only four cases. Table I shows these cases for addition and subtraction.

TABLE I
BINARY ADDITION AND SUBTRACTION

Addition	0	0	1	1	Digit of A
	0	1	0	1	Digit of B
	00	01	01	10	Sum
Subtraction	0	0	1	1	Digit of A
$(A-B)$	0	1	0	1	Digit of B
	00	11	01	00	Difference

If Table I were applied to the addition of two binary numbers of several digits each, the most significant sum digit would be used as the carry into the next most significant position. The effect of a carry of one would be to increase the sum by one. Thus in the jth column or digit position of a pair of binary numbers, eight cases could occur. These are the four of Table I in which there is no input carry, plus the four additional cases in which there is a carry from the $(j-1)$th column. A similar set of statements holds when the word addition is replaced by subtraction, sum by difference, carry by borrow, and increase by decrease. The general practice is to use the words carry and sum to mean also borrow and difference. This is quite justified since subtraction can be regarded as the addition of a number whose coefficients are negative.

Table II shows the eight possible information states at the jth digit position where C_j is the input carry, C_{j+1} is the carry to the next, $(j+1)$th, stage, and S_j is the sum digit.

TABLE II—RULES FOR A BINARY ADDER OR SUBTRACTOR

			Addition		Subtraction	
A_j	B_j	C_j	C_{j+1}	S_j	C_{j+1}	S_j
0	0	0	0	0	0	0
0	0	1	0	1	1	1
0	1	0	0	1	1	1
0	1	1	1	0	1	0
1	0	0	0	1	0	1
1	0	1	1	0	0	0
1	1	0	1	0	0	0
1	1	1	1	1	1	1

Table II can be verified by assigning relative weights to the bits. A_j is to be considered plus 1, B_j and C_j are to be considered plus 1 in addition and minus 1 in subtraction, S_j is always plus 1, and C_{j+1} is plus 2 in addition and minus 2 in subtraction. C_{j+1} must have the relative weight of magnitude 2 since it is to increase or decrease the $(j+1)$th digit position, which has a relative weight of 2 with respect to the jth digit position.

In a Boolean algebraic equation the sum, S_j, would be represented by

$$S_j = \bar{A}_j B_j \bar{C}_j + A_j \bar{B}_j \bar{C}_j + \bar{A}_j \bar{B}_j C_j + A_j B_j C_j \quad (1)$$

(Note that S_j is the same for addition and subtraction.) This is derived by taking the logical "sum" of all the input combinations which are to lead to a sum of 1. The carry, C_{j+1}, would be

$$C_{j+1} = A_j B_j + A_j C_j + B_j C_j \quad \text{(addition)}$$
$$C_{j+1} = \bar{A}_j B_j + \bar{A}_j C_j + B_j C_j \quad \text{(subtraction)} \quad (2)$$

In determining C_{j+1} several logical reductions were made to simplify the expression.

Equations 1 and 2 for S_j and C_{j+1} are the basic equations for a binary adder or subtractor. The physical form varies largely with the mechanization of a serial or parallel operation.

Serial operation corresponds to the familiar paper and pencil method: attention at any one time is fixed on a pair of digits and the previous carry; the sum is determined and recorded; and the new carry is held over for use the next time. During the first time interval, inputs of a serial binary adder or subtractor represent the least significant digits of A and B; during the second time interval, they represent the next most significant digits, and so on. The carry determined in one time interval is entered into a flip-flop so that it will be available for use in the next time interval. The sum digit is entered into a circulating register.

Addition and subtraction will not be done simultaneously and both have the same S_j equation; therefore, an adder and subtractor are usually built with the same set of flip-flops. One flip-flop indicates whether subtraction or addition is to be performed. Figure 1 shows a serial binary adder-subtractor that adds A and B if X equals 0 or subtracts B from A if X equals 1.

In a parallel addition the n digits of B in a multiplicand register (n-flip-flops) are added to the n digits of A in the accumulator register in one time interval. The sum is entered into the accumulator in place of A. There are no carry flip-flops at the digit positions and the C_{j+1} signal in Figure 1 and $\bar{C}_{j+1}$ are provided as inputs to the $(j+1)$th stage. The principal difficulty in parallel adders is that the sum in the most significant digit position may be determined by a carry which originated in the least significant position. For example,

```
  0111111111111
  0000000000001
  -------------
  1000000000000
```

It takes time for the carry to propagate through the circuits at each stage and it is usually necessary to adopt special circuit techniques to make

sure that it does. The magnitude of the problem may be mitigated logically by using more than one time interval to perform the addition (strictly speaking, this is parallel-serial operation). But this reduces the speed advantage of the parallel system. Regardless of the techniques used to solve the carry problem the logical actions at each stage are still given by Equations 1 and 2 for S_j and C_{j+1}. Parallel subtraction is usually done by complementation, discussed later.

DECIMAL SYSTEMS

An arithmetic unit may operate in the decimal mode by representing the decimal digits as combinations (codes) of binary signals. At least four binary signals are required to represent the ten decimal digits. Of the many ways of coding, only a few have been used extensively. One of these is the 8-4-2-1, in which a decimal digit is represented as the equivalent binary number. Another widely used code is the excess-3 code, obtained by adding 0011 (decimal 3) to each representation in the 8-4-2-1 code. By using more than four binary signals, additional redundancies are introduced which facilitate either error checking or recognition of a decimal digit. In the biquinary code shown in Table III, any decimal digit may be recognized by only two signals (the positions of the 1's); should a decimal digit not have two 1's in it, an error exists. In the four-bit codes three signals are needed on the average and a one-bit error may generate another of the used combinations.

TABLE III
EXAMPLES OF DECIMAL CODING

Decimal Digit	Excess 0 or 8-4-2-1	Excess 3	Biquinary
0	0 0 0 0	0 0 1 1	0 1 0 0 0 0 1
1	0 0 0 1	0 1 0 0	0 1 0 0 0 1 0
2	0 0 1 0	0 1 0 1	0 1 0 0 1 0 0
3	0 0 1 1	0 1 1 0	0 1 0 1 0 0 0
4	0 1 0 0	0 1 1 1	0 1 1 0 0 0 0
5	0 1 0 1	1 0 0 0	1 0 0 0 0 0 1
6	0 1 1 0	1 0 0 1	1 0 0 0 0 1 0
7	0 1 1 1	1 0 1 0	1 0 0 0 1 0 0
8	1 0 0 0	1 0 1 1	1 0 0 1 0 0 0
9	1 0 0 1	1 1 0 0	1 0 1 0 0 0 0

An immediate thought in building a decimal serial adder for the 8-4-2-1 code is to add the decimal digits as binary numbers. A few examples would show that in some cases the correct result is obtained but that in other cases the result is incorrect. If 6 and 8 are added,

$$\begin{array}{r} 0110 \\ 1000 \\ \hline 0,1110 \end{array}$$

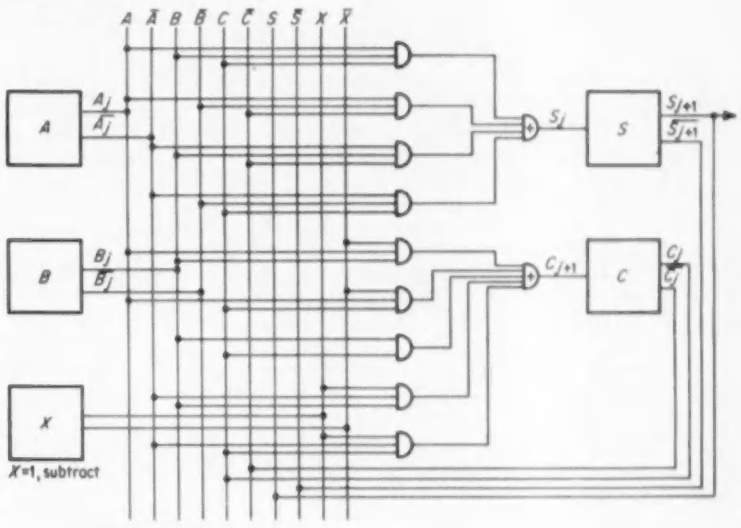


FIG. 1. Serial binary adder-subtractor. For a parallel adder-subtractor the circuit above is paralleled 20 times for 20 digits, the C flip-flop being replaced by a unit with no delay.

the sum is not one of the used combinations and there is no decimal carry. Further analysis shows the difficulty to be that the decimal number sequence jumps from 0,1001 (decimal nine and binary nine) to 1,0000 (decimal ten and binary sixteen), omitting six of the binary numbers. Thus, if the binary sum of two decimal digits is greater than 0,1001, then six (0110) should be added to it to produce the correct decimal result. This "forces" the binary sum to skip the six excluded combinations. Adding six to the result of the above example produces

$$\begin{array}{r} 0,1110 \\ 0,0110 \\ \hline 1,0100 \end{array}$$

which is 14 in the decimal coding.

A serial decimal adder for the 8-4-2-1 code may be built by using a binary adder to produce a binary sum, storing this sum in flip-flops so that it may be examined at the completion of a decimal digit cycle to see if it is greater than 0,1001, and adding 0110 with a correction adder if it is. This sum correction adder may be either parallel or serial. The binary carry signal in the first adder is modified at the start of a decimal cycle if there should be a decimal carry when there was no binary carry.

The excess-3 code has this advantage: the most significant binary carry in each decimal digit group is equal to the decimal carry, because six will always be included in the initial binary sum. The sum correction is made by either adding or subtracting three if the initial binary sum is respectively greater than 0,1111 or less than 1,0000. A simple signal that defines this is the decimal carry or the fifth bit of the binary sum. As a consequence, an excess-3 adder is somewhat simpler than one for 8-4-2-1 coding. A serial decimal adder for the excess-3 code, constructed along the lines indicated for the excess-0 code, is shown in Figure 2.

Subtractors can be built on the same general principles, even to utilizing the same set of flip-flops.

Parallel decimal adders may use gating networks which determine each binary digit of the sum. The inputs to these gates are the codes for two decimal digits with a simultaneous display of the binary sum digits and the carry from the next least significant decimal digit position. These gates may be designed from tables like Table II. In general, each binary digit of the sum is a function of more variables than it is in a parallel binary adder. The carry determination and propagation also assume larger pro-

portions. Hence, there are few attempts to add one decimal operand to another in one time interval.

One way to reduce the problem of adding decimal numbers in registers A and B is to form the partial sum, ignoring carries in A and entering the carries into the B register. During the second time interval the process is repeated, this time adding the first set of carries to the sum. Any new carries that form in this process are reentered into B. Eventually all carries are added to A by repeating this pattern. For example:

B	47639065	
A	31573268	initial time interval
B	01110110	
A	78102223	second time interval
B	00000000	
A	79212333	third time interval

The same technique is applicable to parallel binary adders, but the greater probability of carry generation at each step makes the process liable to run for several cycles, which would destroy the speed advantage of parallel addition. If the binary digits are grouped by three or four and internal group carries propagated speedily through the groups, then the machine is employing an octal or hexadecimal code that reduces the number of cycles in repeated carry additions.

Besides the straight serial or parallel operation, there is another widely used decimal computer arrangement, the serial-parallel. Here the computer is serial in that decimal digits are transmitted sequentially, but parallel in that the binary coding of the digit is transmitted simultaneously. The sum portion of an adder for this arrangement would be parallel and the carry would be serial.

NUMBER REPRESENTATION AND COMPLEMENTS

The problems of number representation involve, principally, how negative numbers may be represented. Both negative and positive numbers may be represented as signed magnitudes. One bit would designate whether the number is negative or positive and the remaining bits would indicate the magnitude. With this representation, though, there may be intermediate results that do not conform to these rules. Using the binary subtractor, consider the result when 1001 is subtracted from 0101,

$$\begin{array}{rr} 0101 & (5) \\ -1001 & -(9) \\ \hline (-1)\ \ 1100 & \end{array}$$

where the 1 set off by parentheses is the borrow that was unfulfilled.

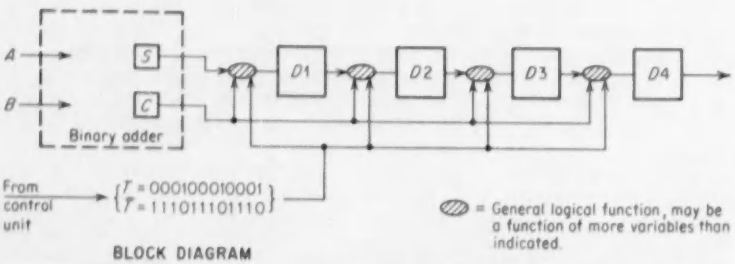
While this result could have been avoided if the 5 had been subtracted from the 9, it may be the case that the subtraction process was used to determine the relative size of two numbers. Also, it is usually time-consuming to determine the larger of two numbers prior to the subtraction process. Thus, it may not be possible or desirable to avoid these subtractions.

Analysis of the result with the weights assigned each bit in Table II shows the result is equal to minus 4. The bits of the difference (1100) have the total positive weight of 12 (8 plus 4 plus 0 plus 0). The unfulfilled borrow has the weight of minus 16 and the total net result is minus 4. Note that a number of magnitude 4 can also be obtained by subtracting 1100 from 10000. This amounts to reversing the signs of 12 and minus 16 and getting this result:

$$\begin{array}{rr} 10000 & (16) \\ -\ 1100 & -(12) \\ \hline 0100 & \end{array}$$

If two numbers produce a sum expressible by a single power of 2 (i.e., 2^n), the numbers are said to be the two's complements of each other. Thus, when positive numbers are being subtracted and there is an unfulfilled borrow at the end of the process (a power of 2), the result is negative and is the two's complement of the true magnitude. Therefore, in the preceding example 1100 is the two's complement of 0100 (decimal 4), and the correct answer is minus 4.

Complementation is useful as a machine process. It permits elimination of either subtraction or addition, e.g.,



BLOCK DIAGRAM

1. When $T=0$, binary sum shifts - S to $D1$, $D1$ to $D2$, $D2$ to $D3$, $D3$ to $D4$, $D4$ to as needed.
2. When $T=1$, C contained decimal carry; $S, D1, D2, D3$ contain the uncorrected binary sum
3. When $T=1$, correct decimal code is determined and entered into $D1, D2, D3, D4$.

CONVENTIONS

Possible conditions when $T=1$						To be entered in each case					
	C	S	$D1$	$D2$	$D3$		$D1$	$D2$	$D3$	$D4$	
(19)	1	1	0	0	1		1	1	0	0	(9)
(18)	1	1	0	0	0		1	0	1	1	(8)
(17)	1	0	1	1	1		1	0	1	0	(7)
(16)	1	0	1	1	0		1	0	0	1	(6)
(15)	1	0	1	0	1		1	0	0	0	(5)
(14)	1	0	1	0	0		0	1	1	1	(4)
(13)	1	0	0	1	1		0	1	1	0	(3)
(12)	1	0	0	1	0		0	1	0	1	(2)
(11)	1	0	0	0	1		0	1	0	0	(1)
(10)	1	0	0	0	0		0	0	1	1	(0)
(9)	0	1	1	1	1		1	1	0	0	(9)
(8)	0	1	1	1	0		1	0	1	1	(8)
(7)	0	1	1	0	1		1	0	1	0	(7)
(6)	0	1	1	0	0		1	0	0	1	(6)
(5)	0	1	0	1	1		1	0	0	0	(5)
(4)	0	1	0	1	0		0	1	1	1	(4)
(3)	0	1	0	0	1		0	1	1	0	(3)
(2)	0	1	0	0	0		0	1	0	1	(2)
(1)	0	0	1	1	1		0	1	0	0	(1)
(0)	0	0	1	1	0		0	0	1	1	(0)

Add 0011 to $S, D1, D2, D3$

Subtract 0011 from $S, D1, D2, D3$

$D1$ input $= C\cdot S + C\cdot D1\cdot D2 + C\cdot D1\cdot D3 + S\cdot D1 + S\cdot D2\cdot D3$

$D2$ inputs $= C\cdot S\cdot D3 + S\cdot D1\cdot \overline{D2}\cdot \overline{D3} + S\cdot \overline{D1}\cdot D2 + S\cdot D1\cdot D3 + \overline{C}\cdot D1\cdot D2\cdot D3 + \overline{C}\cdot D1\cdot \overline{D2}\cdot D3 + \overline{C}\cdot D1\cdot \overline{D3}$

$D3$ input $= C\cdot \overline{D2}\cdot \overline{D3} + C\cdot D2\cdot D3 + \overline{C}\cdot D2\cdot \overline{D3} + \overline{C}\cdot \overline{D2}\cdot D3$

$D4$ input $= \overline{D3}$

COMPLETE INPUTS

$D1$ input $= C\cdot S + T\cdot C\cdot D1\cdot D2 + T\cdot C\cdot D1\cdot D3 + S\cdot D1 + S\cdot D2\cdot D3 + \overline{T}\cdot S$

$D2$ input $= T\cdot C\cdot S\cdot D3 + S\cdot D1\cdot \overline{D2}\cdot \overline{D3} + T\cdot S\cdot \overline{D1}\cdot D2 + T\cdot S\cdot \overline{D1}\cdot D3 + \overline{C}\cdot D1\cdot D2\cdot D3 + T\cdot \overline{C}\cdot D1\cdot \overline{D2} + T\cdot \overline{C}\cdot D1\cdot \overline{D3} + \overline{T}\cdot D1$

$D3$ input $= T\cdot C\cdot \overline{D2}\cdot \overline{D3} + C\cdot D2\cdot D3 + \overline{C}\cdot D2\cdot \overline{D3} + T\cdot \overline{C}\cdot \overline{D2}\cdot D3 + \overline{T}\cdot D2$

$D4$ input $= T\cdot \overline{D3} + \overline{T}\cdot D3$

Binary adder S input $= A\cdot B\cdot C + A\cdot \overline{B}\cdot \overline{C} + \overline{A}\cdot B\cdot \overline{C} + \overline{A}\cdot \overline{B}\cdot C$

Binary adder C input $= A\cdot B + A\cdot C + B\cdot C$

FIG. 2. A serial excess-3 decimal adder.

two quantities may be subtracted by the process

$$A - B = A + (0 - B)$$

The quantity $(0 - B)$ is obtained by taking the two's complement of B on a power of 2 which is beyond the capacity of the register. As a specialized subtraction, the two's complement is not hard to generate. In a decimal machine the equivalent process is the ten's complement, which may also be relatively easy with codes adapted to taking complements.

A simpler complemention process, however, would be to take complements on a succession of ones, or 2^n minus 1, since there could then be no borrow. The resulting one's complement is one smaller than the two's complement and could be converted to the two's complement by adding one. This can be done in a serial machine by presetting the carry flip-flop to 1 before the addition commences. In a parallel machine, a carry would effectively be generated out of the zero-th stage.

Taking the one's complement in a binary machine is particularly simple as 1's and 0's are merely interchanged. The equivalent nine's complement in a decimal machine can be very simple also, as it is in the excess-3 code, where binary 1's and 0's are interchanged.

ADDITION AND SUBTRACTION

The general problem in A plus or minus B for arithmetic units is:

1. Operand A will be in one register, the accumulator.
2. Operand B will be in another, the multiplicand register.
3. The algebraic sum is formed and entered into the accumulator, replacing operand A.

After 1 and 2, above, are accomplished, the operational sign (plus or minus) of the order (add, subtract) is combined with the sign of B to determine the machine operation. B is then considered to be positive and is added or subtracted as determined by the machine operational sign.

Consider the two simple cases using 3-bit registers where A equals 0, B equals $\frac{5}{8}$ and A equals 0, B equals minus $\frac{5}{8}$.

				Register
.000	(0)	.000	(0)	accumulator
+.101	+(5/8)	−.101	−(5/8)	multiplicand
.101	(5/8)	.011	(−5/8)	accumulator
no carry from the accumulator		a borrow (carry) from the accumulator		

(Places to right of binary point are negative powers of 2; i.e., 2^{-1}, 2^{-2}, 2^{-3}, etc. Thus, .101 equals $\frac{1}{2}$ plus 0 plus $\frac{1}{8}$, or $\frac{5}{8}$.) The result in the second case is negative and expressed as the two's complement of the magnitude. The absence of a carry-out in the positive case and the presence of a carry-out in the negative case suggest a procedure for the simple determination of the sign of the result. This is to extend the registers by one bit and make the most significant bit the sign digit, where the same arithmetic operations are performed upon the sign digits. Zero can represent a positive number and 1 a negative number. For the two cases above, there would result

0.000	(0)	0.000	(0)
+0.101	+(5/8)	−0.101	−(5/8)
0.101	(5/8)	1.011	(−5/8)

where the initial sign convention still holds for the result.

Examples with non-zero values for A follow, illustrating combinations of signs and magnitudes of A and B. A is expressed as a complement if it is negative. Also, to illustrate the use of complements to replace subtractions, the binary values for B, including sign, are shown as a complement if a complement is to be added. In a parallel machine this complement is generated prior to the addition. In a serial machine it would be formed serially at the adder input during the addition process.

ADDITION, $A + B$

A	0.01	(1/4)	0.01	(1/4)
B	0.10	(1/2)	1.10	(−1/2)
	0.11	(3/4)	1.11	(−1/4)
A	1.11	(−1/4)	1.11	(−1/4)
B	0.10	(1/2)	1.10	(−1/2)
	0.01	(1/4)	1.01	(−3/4)

SUBTRACTION, $A - B$

A	0.01	(1/4)	0.01	(1/4)
B	1.10	(1/2)	0.10	(−1/2)
	1.11	(−1/4)	0.11	(3/4)
A	1.11	(−1/4)	1.11	(−1/4)
B	1.10	(1/2)	0.10	(−1/2)
	1.01	(−3/4)	0.01	(1/4)

In determining the magnitude of the result in the negative cases, note that the sign digit is not complemented because it is correct.

In serial systems the operand B is stored in the multiplicand register prior to addition or subtraction so that its sign can be determined. In parallel systems, the amount of equipment needed to add from an arbitrary memory location into the accumulator demands that the operand be entered into a register for addition. The operand A is entered into the accumulator by the same path: memory to multiplicand register to accumulator. However, the accumulator would be reset or cleared prior to the addition or subtraction of A so that 0 plus or minus A would be entered. Add or subtract can be performed with the basic arithmetic unit of two registers and adder, Figure 3.

MULTIPLICATION

Multiplication can be analyzed by reference to manual methods. There are three distinct phases in arriving at the result. Take the two examples,

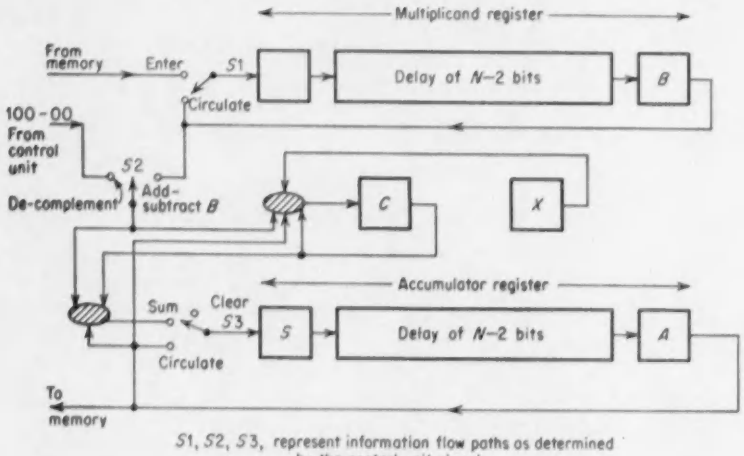
726	multiplicand	1 0 1	(5)
439	multiplier	0 1 1	(3)
6534		1 0 1	
2178	partial products	1 0 1	
2904		0 0 0	
318714	product	0 1 1 1 1	(15)

▶ One phase of the solution generates the partial products, i.e., the product of one digit of the multiplier times the multiplicand. A human has recourse to a "built-in" multiplication table which, along with the addition of carries, enables him to determine the partial products. The determination of the partial product for binary numbers is extremely easy for both humans and computers. If a binary multiplier digit is 1, the multiplicand is the corresponding partial product, while if the multiplier digit is 0, the corresponding partial product is zero.

The determination of the partial product for decimal computers is not so easy. A relatively simple means reverts to counting techniques and repeated additions. The multiplier digit is put into a counter which counts to zero. For each count the multiplicand is added once so that when the counter reaches zero, the partial product has been formed. The equipment needed above that required for addition are the counter and control circuits.

Another important method, used mainly in serial-parallel computers, uses a built-in multiplication table. The inputs are two decimal digits with a simultaneous display of the binary bits. The output consists of the binary bits of the two-digit product. Between the outputs and inputs are a series of "AND-OR" gates. The least significant digit of the two-digit product is added to the previous carry. The new carry is determined by the most significant digit of the product plus any carry from the previous addition. Because the carry can range from 0 to 9, a more complex adder is required than that for addition.

▶ The second phase of the solution is the shifting, or multiplication, of the partial products by powers of the radix. In the example above, the 4 in



S1, S2, S3, represent information flow paths as determined by the control unit signals

To perform the addition of $A+B$, S1, S2, S3 would be in the following condition:

	S1	S2	S3
Read A from memory*	Enter	—	Clear
Add $0+A$	Circulate	Add-subtract B	Sum
Read B from memory*	Enter	—	Circulate
Add $A+B$	Circulate	Add-subtract B	Sum
De-complement**	Circulate	De-complement	Sum
Circulate (as needed)	Circulate	—	Circulate

* At the end of this work time X is set to add or subtract as need be.
** May not be necessary; if it is, X is set for subtract.

FIG. 3. Serial arithmetic unit for addition and subtraction takes operands from memory and returns sum to memory.

the multiplier stands for 400. The partial product 2904 is 4 times 726, but by being shifted left twice with respect to 6534 it is equivalent to 290400.

In general, if r is the radix of the number system, a shift of a number with respect to another number or to an imaginary radical point by n digit positions corresponds to multiplication or division by r^n. A shift to the left corresponds to multiplication and a shift to the right is equivalent to division. A shift is easy to visualize in a parallel machine, but more difficult in serial machines, where the numbers are continuously circulating. If it is remembered that the reference number is circulating too, it is seen that a left shift can be mechanized by adding delays to the circulation path and a right shift, by removing normally present delays from the circulation path. Thus multiplication or division by the number system radix is easy to perform in a computer.

► The third phase is to find the sum of the various partial products. On paper, where storage is relatively cheap, it is the practice to obtain all the partial products before summing. In arithmetic units, where storage is not cheap, it is easier to add each partial product as it is formed to the sum of the preceding partial products. Before the addition of the partial product, the partial sum is shifted right. The next partial product is then multiplied by ten with respect to the partial sum.

The final sum, which is the product, is $2n$ digits long if two n-digit numbers are multiplied together. It would appear that four one-word registers are necessary. However, three one-word registers suffice. After each digit of the multiplier is used, there is no need to retain it; thus, a digit of storage becomes available in the multiplier register. Also, after each of these cycles the least significant digit of the partial sum is not subject to later change. This digit may be transferred to the vacated position in the multiplier register.

To illustrate this procedure 583 will be multiplied by 212, as it would be in a decimal machine that uses repeated additions to obtain the partial products.

Initially, the multiplicand register holds 583, the accumulator register holds 000, and the multiplier register holds 212. The least significant decimal position of the multiplier register is a counter which holds the current multiplier digit, and the accumulator register can accumulate four-digit sums.

Multiplicand	Accumulator	Multiplier	
583	000	212	initial condition
583	583	211	add multiplicand twice
583	1166	210	
583	116	621	shift
583	699	620	add multiplicand once
583	069	962	shift
583	652	961	add multiplicand twice
583	1235	960	
583	123	596	shift

Product = 123,596

For a $2n$ digit result, the most significant n digits are found in the accumulator register and the least significant n digits in the multiplier register. For the most significant half to contain as much information as possible, each of the factors must be as close as possible to maximum representation. In other words, each factor should contain as much information as possible in its most significant half. It is more convenient to consider numbers scaled in this manner as being less than one in magnitude, rather than as integers.

DIVISION

Division is the process of determining how many times the divisor is contained in the dividend. In the division 988/13, the 13 could be subtracted 76 times and a positive balance would remain. On the 77th time there would be a negative balance, which indicates the quotient is between 76 and 77. Just where would depend on the remainder, which can be obtained by adding 13 to the negative balance. But this solution is essentially a counting scheme, which is very slow.

If the 13 is multiplied by ten so that it appears as 130 before the initial subtractions, each of these subtractions is equal to ten of those above. On the eighth cycle a negative balance appears, which indicates that the quotient is 70 or more and less than 80. Adding 130 to this negative balance gives a positive balance of less than 130. At this point, 130 can be divided by 10 and a series of subtractions made to determine the units quotient digit. This method is readily extended to larger numbers with as many divisions by ten as there are quotient digits. It is the inverse of repeated additions in multiplications.

A usual program requirement is that the divisor be larger than the dividend. This means that the divisor is initially scaled correctly and that the trial subtractions can begin immediately. The quotient is then less than one and an interpretation of the numbers as being less than one is convenient.

In the machine mechanization, a radix division of the divisor at the end of each quotient digit cycle would mean a right shift of the divisor. As the problem proceeds digits of the divisor would be shifted out of the register, destroying this information. The partial balance, though, is reduced to less than the divisor at the end of each quotient digit cycle. This partial balance can be multiplied by ten, the effect being the same as dividing the divisor by ten. Then no information is lost.

In decimal division, the divisor is stored initially in the multiplicand register and the dividend in the accumulator, and the multiplier register is cleared. The following program is then repeated until all the quotient digits have been generated.

1. Shift the accumulator contents to the left by one radix position. (Assume the accumulator has a more significant digit position than the other registers.)
2. Subtract the divisor from the accumulator.
3. Count up 1 for the quotient digit if the accumulator is positive and repeat steps 2 and 3. If the accumulator is negative proceed to 4.
4. Add the divisor to the accumulator to get a positive balance.
5. Shift the multiplier register left and insert the quotient digit in the least significant position.
6. Repeat 1 through 5 until the required number of quotient digits has been generated.

At the end of this program, the multiplicand register contains the divisor, the accumulator contains the remainder, and the multiplier register contains the quotient.

The same principle holds for binary division. Since each quotient digit is 0 or 1, only one trial subtraction is made for each. If the balance is negative the quotient digit is 0 and if positive the quotient digit is 1. Step 4 can be eliminated.

As given above, whenever a negative balance is obtained the divisor is added to correct this overdraft. This correction can be made after shifting the partial balance if it is noted that the error in the balance is shifted also. The correction can be combined into one operation with the trial subtraction for determining the next quotient digit. After shifting a negative balance to the left the divisor should be added twice for correction. Combining this operation with the trial subtraction of the divisor, the net operation is to add the divisor once. Steps 2, 3, and 4 then become:

- ▶ negative balance—add divisor next time, quotient digit equals 0.
- ▶ positive balance—subtract divisor next time, quotient digit equals 1.

Both multiplication and division have been discussed as operations on positive numbers. The operations are also applicable for negative numbers given as magnitudes. And complements can be used directly with modified techniques.

BRANCH ORDERS

A great deal of the power and flexibility of digital computers come from their decision ability. This, in turn, is the result of the branch orders: orders in which there is an alternate next step, or address. The choice between these addresses could be determined by the sign associated with a register, by whether the contents of a register are zero or non-zero, by the relative size of two numbers, or by whether an uncorrected overflow condition exists. The exact choice of conditions depends on the machine. Parallel machines generally subtract one number from the other and use the sign of the result as the branch conditions. Note that in serial computers the carry flip-flop in subtraction determines whether or not *B* is larger than A. Branch orders are usually easy to mechanize in the arithmetic unit; the problems are control problems of selecting alternative addresses.

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(And previous articles in this series)

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Radar Antenna Checked in Simulated Flight

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For precision applications of aircraft radar, antenna attitude must be unaffected by aircraft maneuvers. In effect, the antenna must be a free body, independent of aircraft attitude. Ideally, these requirements might be met if the antenna were mounted in a frictionless gimbal with perfect balance. Practically, it is not possible to achieve this ideal condition because of bearing friction, balance compromises, electrical cable drag, slip ring friction, etc.

Precisely controlled torques, derived from a stabilization system and applied to the antenna's gimbals, balance out detrimental coupling effects. This assures space-stabilized antenna operation for mapping, precision bombing, navigation, and tracking. Simulation of the physical maneuvers of aircraft motions (pitch and roll) on a land-based test stand minimizes in-flight testing time and allows economical development, testing, and evaluation of the dynamic performance of the stabilization system.

ANTENNA STABILIZATION SYSTEM

Operation of the stabilization system lays down the basic specifications for test stand performance. The stabilizing device contains several servomechanisms. A servo motor exerts

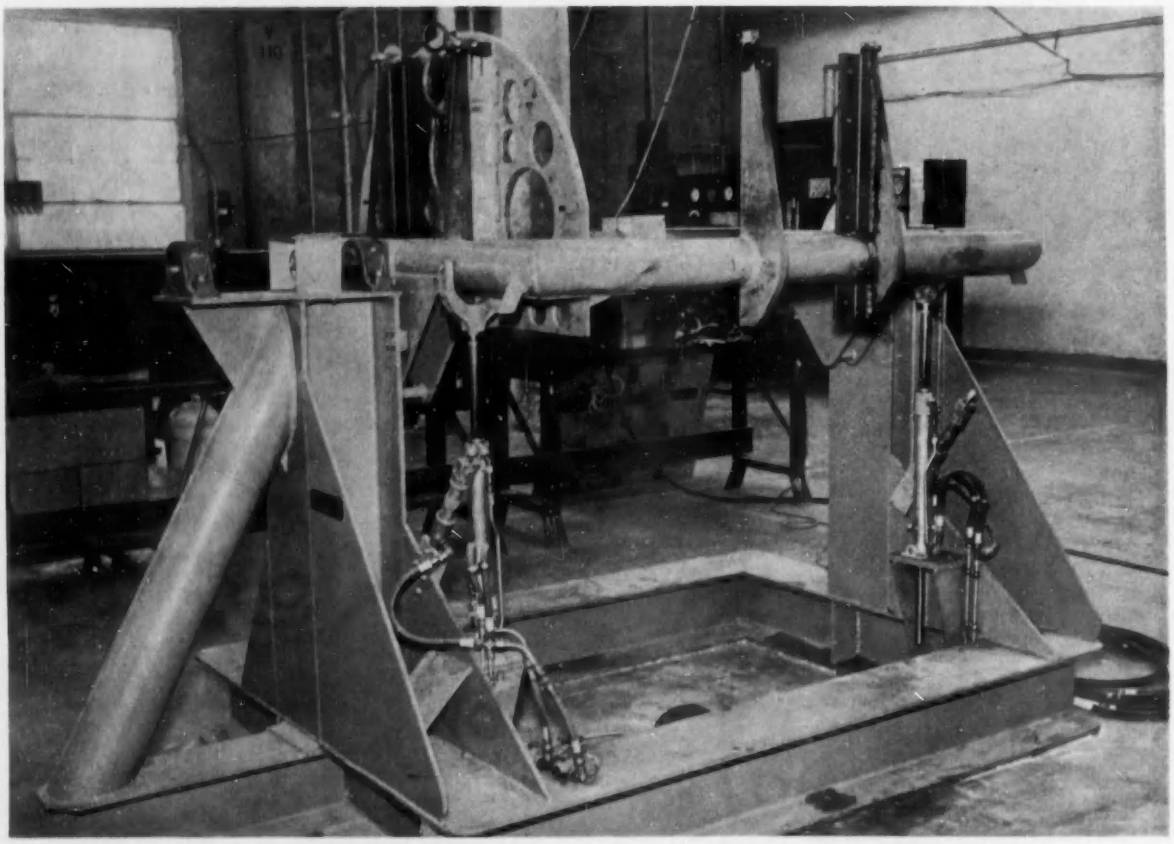

FIG. 1. This view of the hydraulic test stand shows two cylinders that oscillate the movable platform about its horizontal axis. Here both mounting brackets for pitch and roll maneuvers are attached.

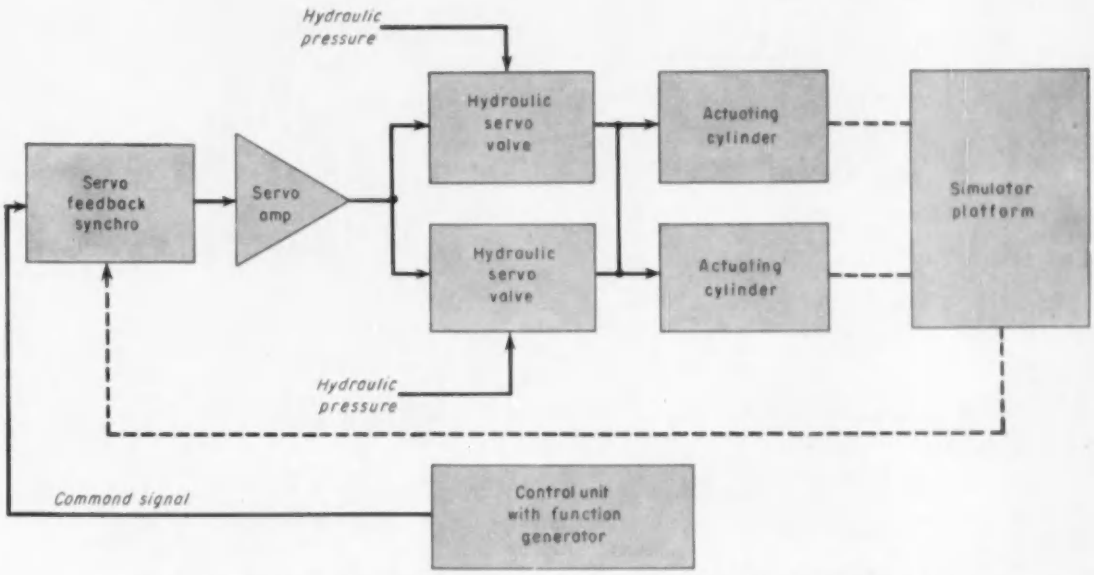

FIG. 2. The block diagram of the radar stabilization system test stand indicates generation of command signals within the control unit, the amplification of the signals, and their subsequent operation of the valves and cylinders. The complete system is closed-loop operated to assure that the platform follows the position commanded by the function generator.

torque on each gimbal axis. Electrical signals that control these motors originate in a gyroscope mounted on the antenna gimbal. Any change in attitude experienced by the antenna is also felt by the gyroscope, which generates a correction signal that drives the appropriate servo motor and thus corrects antenna attitude.

The stabilization system error voltage serves as a measure of the radar system's performance. The voltage is directly related to the difference between antenna position in space and the gyro motor position in space, and the variations of its magnitude, frequency, and phase angle are easily measured.

TEST STAND REQUIREMENTS

A typical radar weighs about 250 lb and occupies a space about 40 in. in diam and 40 in. in depth. Structurally the test stand (Figure 1) must be able to support its cantilever load while it subjects the radar to pitch and roll. All parts must be structurally stiff because excessive compliance (less stiffness) may result in unstable and unsatisfactory operation, particularly during frequency response tests when the stand oscillates at high frequencies.

To simplify design, only one degree of freedom is considered necessary, that of rotation about the horizontal axis. Attachment points on the test stand permit the radar to be mounted with either its roll axis or pitch axis coaxial with the rotational axis of the stand. Aircraft motions are synthesized by driving the test stand's movable platform angularly and sinusoidally. Typical maximum design values include an amplitude of plus or minus 12 deg, a velocity of 60 deg/sec, and an acceleration of 300 deg/sec^2.

TEST STAND DESIGN

Oscillating the high inertia load requires a driving power in excess of 5 hp. Practical considerations indicate generating and controlling the oscillation signals with an electronic function generator that delivers low-power signals. Previous experience suggested that necessary power gain could be obtained with hydraulic actuators controlled by electrohydraulic servo valves. Thus a low-level electronic signal drives the high-power hydraulic motor, as shown in Figure 2.

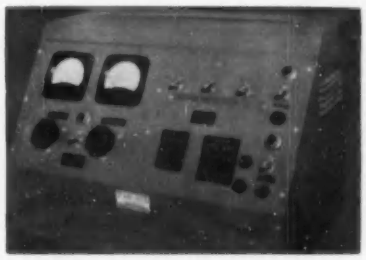

FIG. 3. The control unit with function generator feeds command signals to the electrohydraulic servo valves, which in turn control the cylinders and drive the test stand's movable platform.

The test stand uses two balanced hydraulic cylinders of 1.289-in.^{2} piston area and a 10-in. stroke. These cylinders, located close to a test-stand bearing, reduce bending moments and stresses on the test stand. Hydraulic cylinders are connected in parallel so that differences in valves will not stress the structure. Two Moog Model 1400 hydraulic servo valves of 10 gpm max flow capacity are used in parallel to drive the cylinders. (One valve of 20 gpm capacity could be used now that they are available). A 3,000-psi hydraulic fluid inlet pressure at the cylinder may develop an acceleration of 400 deg/sec^2 on the load. The servo valve electrical inputs also are connected in parallel. Valve performance is nearly identical and entirely satisfactory operation has been experienced.

The test stand and its associated electronic function generator also operate as a closed-loop system. A synchro for position feedback is coupled to the rotating axis at one end of the test stand. Thus the test stand closely follows the command signal of the function generator. Moderate loop gain assures smooth operation of the test stand.

MODEL VRSAC750
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Input current	7 amperes maximum
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SIZE 20⅝" high, 19⅜" wide, 12" deep WEIGHT 115 pounds net

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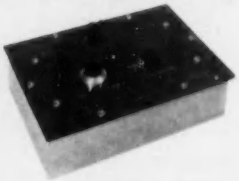

Output voltage range	10 mv to 10v RMS in three ranges
Calibration accuracy	±0.1% at full scale at 60 cps
Input voltage	115v ±10%, single phase
Input frequency	50-60 cps; to 400 cps with slightly less accuracy
Waveform	Distortion is negligible
Regulation with load	0.25% max., with load resistance higher than 0.5 megohm
Regulation with line	±0.25% max.

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CONTROLLED POWER FOR RESEARCH AND INDUSTRY

Automatic "Mike" Uses Forwardlash

MAX FOGIEL, Ford Instrument Co.

Although the diagrams shown here may tend to indicate otherwise, simplicity and economy were the targets of this design for an automatic micrometer. Performance accuracy in the range of 0.0001 in. for a highly variable set of products was a design specification. Output is a shaft rotation, and the average measurement is made in 11 sec.

The basic scheme is shown in Figure 1. The screw is calibrated accurately in integral inches only. But the rack and pinion is accurate throughout its 1-in. range. The screw is rotated until the movable jaw's tongue is depressed and then is stopped at the next integral inch position. The movement of the tongue with respect to the movable jaw is automatically subtracted from the rotation of the screw by the differential, whose output then indicates the true diameter of the measured shaft.

This arrangement is sufficient if all the components are accurate enough. In practice, however, there are inaccuracies in the screw and in transmission to the differential. These can be disposed of by the circuit shown in Figure 2 without high precision or costly components.

Clutches connect a drive motor to both the measuring jaws and to the differential. By relay-actuating these clutches one before the other, the proper amount of "forwardlash" can be introduced into the output differential to compensate for the backlash found to exist elsewhere.

Since the screw will position the movable jaw to integral inches only, the screw need display high accuracy only at these points. The contacts of the cam and switch set attached to the screw are closed only when the screw is at integral inch positions. In series with these contacts is a snap-action switch operated only when the movable jaw's tongue is depressed. As the screw might be rotating rapidly at the instant of contact, a monostable multivibrator holds this circuit closed.

The circuit pulls in relay 1; relay 1 operates relay 4, and relay 4 opens clutch A and operates lock B. With the operation of relay 1, a circuit is made for the operation of relay 3

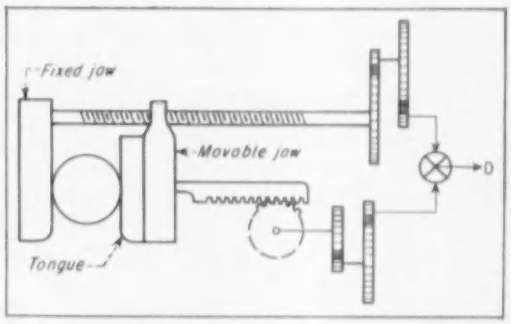


FIG. 1. The measurement device's basic elements. A differential is used to subtract the motion of a movable tongue relative to a movable jaw from a rotating screw calibrated in increments.

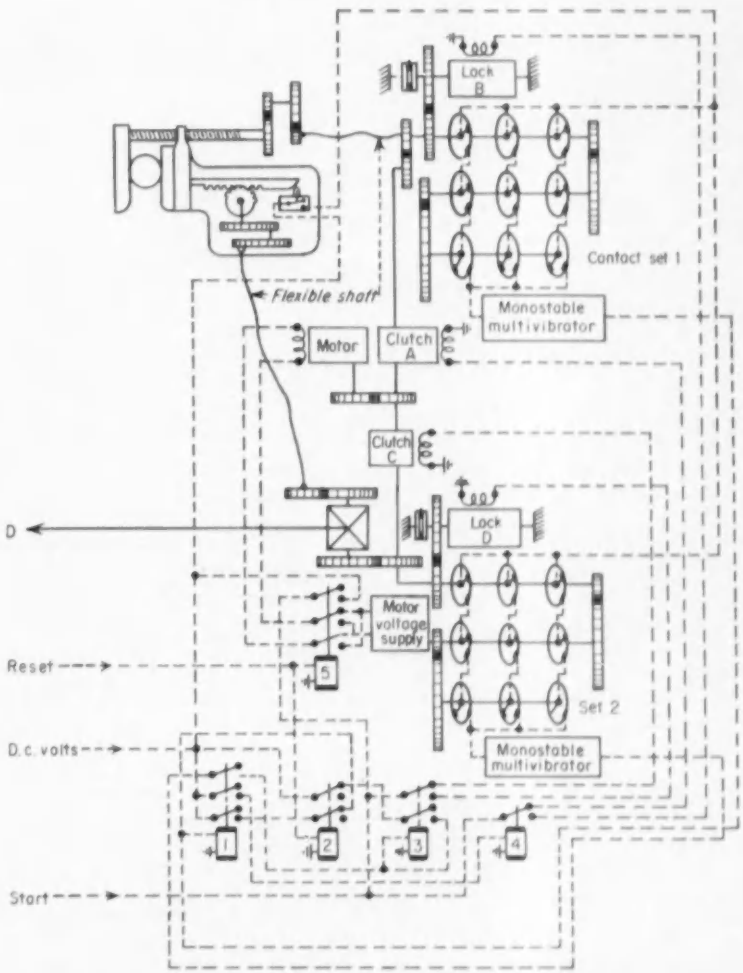
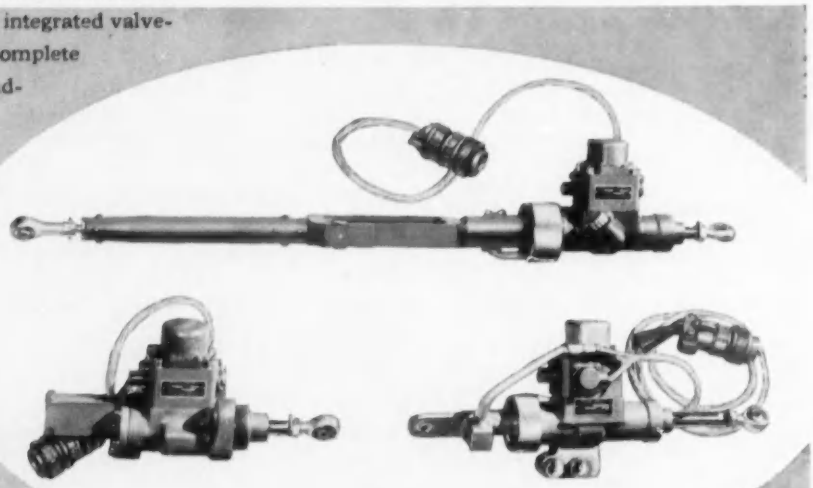


FIG. 2. The complete circuit for the system, showing how clutches and contacts respectively introduce corrective displacements and indicate shaft positions.

From MOOG... **Integrated Electro-Hydraulic Servo Actuator Units**

▶ Industry today has many new requirements for special actuators for use in high-performance electro-hydraulic servo systems. The Moog Valve Company, Inc., as a leading servo valve manufacturer, recognizes a need for these components to be supplied as integrated valve-actuator assemblies. Such complete actuator packages offer the advantages of a comprehensive custom design including reduced overall complexity and minimum size and weight.



These package units available from Moog include an actuating cylinder, an electro-hydraulic servo valve, and a feedback sensing device. In combination with a suitable electronic amplifier they provide control of actuator displacement as a function of input signal. Overall performance is characterized by high dynamic response, linearity, and excellent resolution.

To meet special requirements, assemblies can be provided which include such auxiliary devices as shut-off or by-pass solenoid valves, force limiting relief valves, and piston locks.

MOOG

MOOG VALVE CO., INC. PRONER AIRPORT, EAST AURORA, N. Y.

upon the closing of contact set 2. The operation of relay 4 has a brief time delay to match irregularities in the screw thread. Relay 4's delay produces the "forwardlash".

The clutches on the same shaft with the locks are constant friction types, which compensate for irregular energization of the clutches in the retracting cycle.

One aspect of the circuit that is not too easy to see is the reason for two sets of contacts. Note that the action of contact set 2 is effective only after set 1 has closed relay 1. So long as contact set 2 closes after set 1, a positive correlation of shaft angles is maintained. In effect, this arrangement says, "When the screw reaches integral inch points, it stops, after certain fixed delays. When the input to the differential reaches integral inch positions, it stops." The ambiguous connection which the clutches create is thereby compensated for, but without affecting the possibility of introducing an adjustable angular difference between the two shafts. Although the components of this system operate consistently from performance to performance, a variable delay could be used with relay 4, enabling a nonlinear angular displacement between the differential and the screw over various portions of the screw's range.

The system has errors when the jaws are being "backed off", but these are of no import as no measurements are made during this action.

Sample Flue Gases Without Dirt

Steam ejection, condensation by water jet, and centrifugal separation provide a washed, acid-free sample to a flue gas oxygen content analyzer. Hence, an open hearth flue gas sampling system with no maintenance headaches.

The percentage of oxygen in the flue gas of an open hearth furnace is a good index of furnace performance. Oxygen content can be measured reliably with magnetic oxygen analyzers (oxygen is strongly attracted by magnetic fields), and this measurement permits faster heats and increased steel production. The problem is to get a continuous, dirt-free sample without lots of maintenance.

A new approach was used by Leeds & Northrup for an oxygen analyzer installation at Jones & Laughlin Steel Corp. in Pittsburgh. In this installation, a recorder-controller adjusts the fuel-air ratio automatically for optimum combustion efficiency.

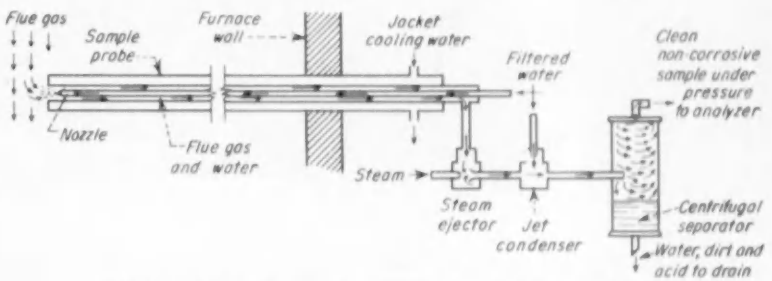


FIG. 1. A flue gas sampling system that will deliver a clean sample to an oxygen analyzer with a minimum of maintenance.

FIG. 2. A magnetic oxygen analyzer (below) and a recorder-controller on an open hearth furnace panel board.

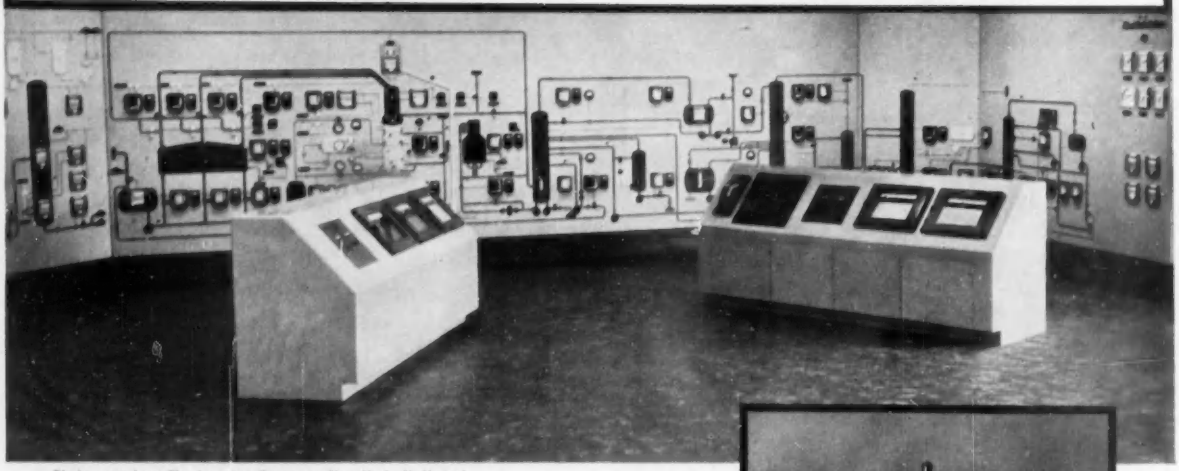
SAMPLER DESIGN

The new sampling system is illustrated in Figure 1. It uses a water-jacketed probe, a steam ejector, a jet condenser, and a centrifugal separator. Each of these is necessary to continuous, trouble-free sampling. The water jacket cools the tube against the effects of the very high temperature flue gas. The center tube in the probe carries filtered water to a nozzle which washes the probe opening with jets to keep it free of slag. Small radial sprays flush the sample passage to prevent the accumulation of dirt.

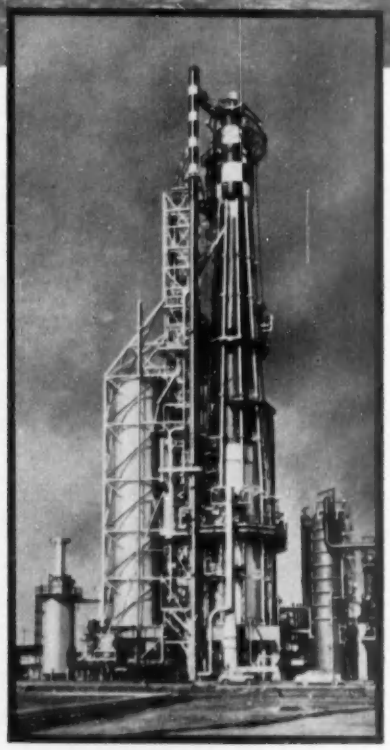
The suction of the steam ejector draws the mixture of flue gas and wash water from the probe. Steam mixes thoroughly with the gas and dirt, and the mixture passes to the jet condenser. In the condenser, a water jet condenses the steam and wets the dirt particles. The condensation also removes corrosive gases. The centrifugal separator spins water and wet dirt out of the gas and drains them off at the bottom.

The clean gas sample leaves the top of the separator, and is delivered to the analyzer under positive pressure. This pressure causes a fairly high velocity in the tubing to the analyzer, reducing the chances of sample contamination due to leaks in the tubing. Thus, the sample delivered to the analyzer is scrubbed and acid-free, while plugging and corrosion of the sample line are practically negligible.

"American-Microsen" Electronic Control chosen by PETROFINA on proved performance



Photos courtesy The Lummus Company, New York, N. Y. and Canadian Petrofina Ltd., Montreal, P. Q.



This is the new refinery of Canadian Petrofina, Ltd., at Point aux Trembles, Quebec. Located here is the first Catalytic Cracking Unit in the Western Hemisphere to be operated by the "American-Microsen" Electronic Process Control System. It is the latest of hundreds of installations that have proved the reliability and practical advantages of "American-Microsen" control for refineries and chemical plants.

This Petrofina installation demanded long-distance transmission and difficult control applications, but start-up was completed ahead of schedule—to the benefit of refinery and contractor. *And the installed cost of the instruments was the same as for conventional controls.*

The long list of successful "American-Microsen" applications includes plant-scale operation of numerous critical petroleum and chemical processes. Conventional instruments could not control some of these processes, but they are handled easily by "American-Microsen" because of its speed of response, sensitivity and lag-free transmission. Many of these installations have been functioning well over a year, without maintenance problems, and with the enthusiastic approval of users.

You want better control and simplified servicing in automating your processes for higher product quality and greater economy. The "American-Microsen" Electronic Process Control System assures both—on new units and those now impossible to control satisfactorily. Invite one of our field sales engineers to help you determine the best equipment for your requirements without obligation, of course.

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INDUSTRIAL CONTROLS DIVISION, STRATFORD, CONNECTICUT

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Digits and Optics Team For Precision

Sixteen-bit code wheels for high-precision analog-to-digital converters demand special manufacturing tolerances and techniques. A new machine uses electronic digital techniques and an optical approach to reduce hundreds of hours on a dividing engine to about two hours. Moreover, it makes 16-bit discs easily, whereas dividing engines failed to produce a single satisfactory 15-bit disc.

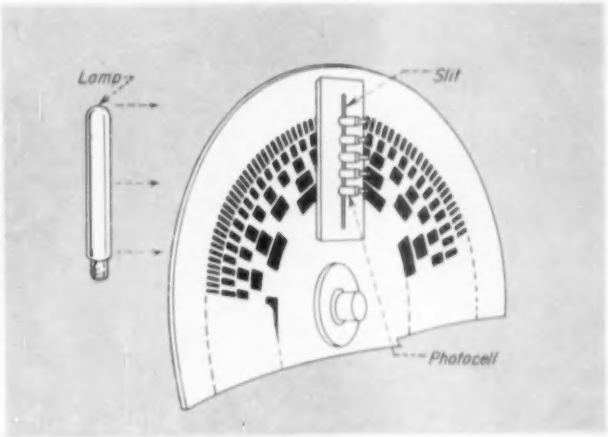


FIG. 1. An optically-read code wheel for analog-to-digital conversion.

E. M. JONES
The Baldwin Piano Co., and
B. LIPPEL and K. M. DOERING
Signal Corps Eng'g Labs.

For analog-to-digital code wheels, the number of angles to be resolved varies exponentially with the number of binary digits generated. To increase the number of binary digits that can be encoded on a reasonably small disc, very high angular resolution is necessary and optical techniques become preferable to capacitive, inductive, or conductive means for signal take-off. Figure 1 illustrates an optically-read disc that uses alternately opaque and transparent pattern elements.

Figure 1 shows a 5-bit code. For a 16-bit code, with the least significant bit "recorded" at an 8-in. diam, the transparent and opaque elements on the outermost zone would be crowded together 1,300 to the inch. These must be distinguished accurately, which is not too difficult optically (even with very comfortable clearances between disc surfaces and stationary parts). The real difficulty is that the angular boundaries of the code pattern must be laid out very accurately. Once a good master disc is obtained, high resolution photographic emulsions make possible satisfactory reproduction by direct contact printing.

All radial pattern boundaries for code patterns for the binary cyclic code or its decimal relatives should be accurate to plus or minus one-half the quantum angle. On an innermost ring of 5 in. diam in a 16-bit coder, this tolerance is plus or minus 0.00013 in. in linear distance. Several attempts were made some years ago to engrave and etch a 15-bit pattern with a 9-in. OD through a metal coating on glass. A conventional circular dividing engine (designed for mechanical engraving) was used to engrave the fine zones and the boundaries of the larger zonal sectors. These attempts failed due to engraving and programming trouble.

MAKING THE PATTERN

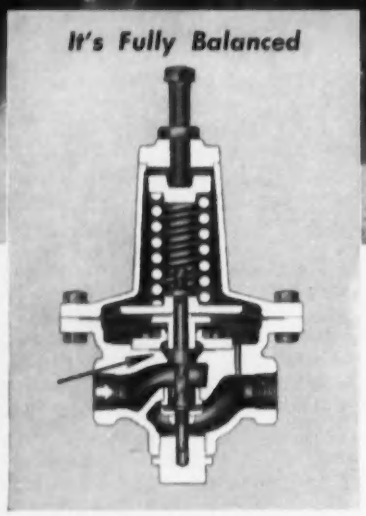
A special machine designed by Signal Corps and Baldwin engineers and built by The Baldwin Piano Co. now makes the master disc photographically in a variety of codes and sizes. An unexposed photographic plate is clamped to the top of a turntable that rotates with uniform velocity. A beam of light is projected from above to expose one zone or "track" on the plate. The light beam is modulated to produce a latent image of the alternately transparent and opaque sectors in the zone. The modulation frequency is derived by frequency division from a reference signal which is generated photo-electrically from a large (16-in. diam) glass ring carrying evenly spaced radial marks, which is mounted below the table and rotates with it, as shown in Figure 2.

For binary code discs, the reference track has 2^{16} or 65,536 lines. A binary counter chain of 16 flip-flops successively divides the reference frequency by two. A square wave signal is tapped off from each flip-flop in turn to make successive zones of the pattern. The glass ring attached to the turntable has eight reference tracks. For other than binary codes some of the counter flip-flops are replaced by circuits that divide by more than two, and a reference track with a suitable number of lines (not necessarily 2^{16}) is chosen.

The table also generates a reset pulse at one fixed point in its revolution. This pulse returns the whole flip-flop chain to an initial setting, which insures correct orientation of the angular boundaries of each track relative to the other tracks, even if the turntable is stopped between the exposure of different tracks.

The marks on the reference pattern are presently accurate to about plus or minus 3 sec of arc, but it is expected that more accurate reproductions will be made on the machine itself by combining and rerecording the signals from more than one photocell. A similar averaging technique

Here is the new LESLIE "HI-FLO" Water Reducing Valve with 50% more capacity



Unique construction of "Hi-Flo" Reducing Valve. Note the small lower diaphragm that provides fully balanced, floating action.

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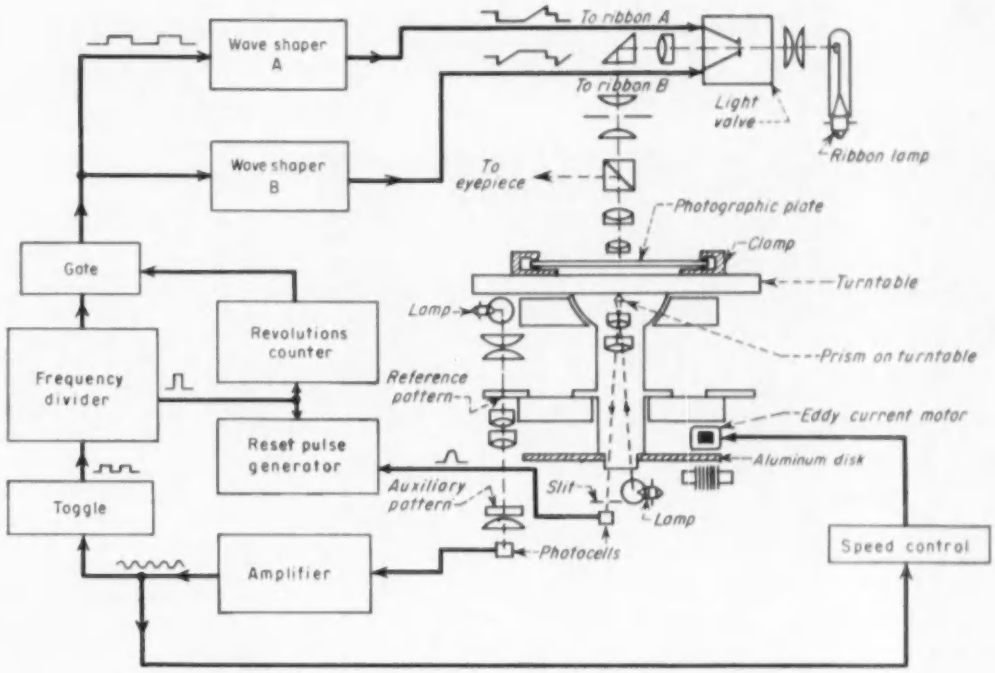


FIG. 2. Block diagram-schematic of the photographic disc-making machine.

is presently used in reading the reference pattern. Light is projected through the rotating reference pattern and a matching stationary pattern onto a germanium photocell. Due to the extent of the stationary pattern, the photocell receives the integrated effect of about 60 divisions of the reference pattern. This makes the effects of dust and defects on the pattern negligible.

LIGHT MODULATION

The signal from the reference photocell is essentially sinusoidal, and is converted to a steep-fronted square wave by a "toggle" flip-flop. This square wave is then divided by the counter chain to get new square waves, each of a frequency suitable for a particular circle of the code pattern.

The counter output for the track being exposed is gated and then fed, via two parallel wave-shaping circuits, to the two ribbons of a Westrex light valve—a light modulator designed for motion picture sound recording. The gate opens for an integral number of turntable revolutions determined by counting the once-per-revolution reset pulses. It is manually preset to determine the track exposure time. A typical exposure for a 5-in. diam track is 8 revolutions at 3 rpm, on Eastman High Resolution emulsion.

The Westrex light valve has two independently movable ribbons. The space between the ribbons forms a slit which can be adjusted by varying the current through the ribbons. At rated current the ribbons separate by 0.001 in., which is reduced optically to an image 0.0004 in. wide. For sound recording, the ribbons are connected in series and move equally and oppositely. In this case, dissimilar voltages from the two waveshapers, *A* and *B*, are applied to the ribbons.

The waveforms applied to the light-valve ribbons are shown in Figure 2. The slope of the slanting part of the waveform is such that the speed of the ribbon image corresponds to the linear speed of the photographic plate; consequently, the image stands still momentarily with respect to the plate and a sharp boundary is photographed. The ribbon motion goes as follows: starting from a dark, closed-valve condition, one ribbon, moving at a speed to keep its image fixed on the moving plate, opens the valve; the valve may remain entirely open for some time, depending on the length of the sector being exposed; then the second ribbon closes the valve by moving at the same speed as the first. Both ribbons move back to the starting point together, to keep the valve closed. Thus, the boundaries are kept sharp and every area of the sector gets the same exposure.

The turntable is driven by an eddy current motor. An aluminum disc attached to the turntable serves as the rotor for the drive motor, which is part of a servo speed control system. The servo monitors the signal from the reference disc to control the speed. It was incorporated more to widen the speed range of the system than to maintain absolutely constant speed. With the servo, the speed is adjustable between 1/15 rpm and 20 rpm, permitting reasonable exposures at all diameters within the range of the machine.

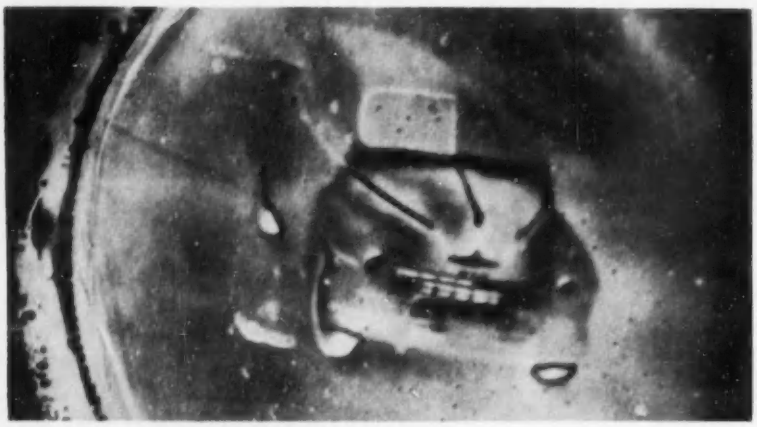
MECHANICAL FEATURES

The photographic code disc maker has some interesting features mechanically, too. To benefit from the high resolution capabilities of the optical systems, the turntable must be made, and must rotate in its bearings, with extreme precision. In fact, the turntable in question is made with optical precisions and the bearing in which it turns runs about a true center within one wavelength of light. This is an air bearing to reduce friction and eliminate the effects of wear—the whole rotating assembly hovers on an air cushion 0.001 in. thick. The mechanical features of this machine are discussed in more detail in *Product Engineering*, McGraw-Hill Publishing Co., April 1956.

NEW PRODUCTS

LISTING IN GROUPS

1- 6 Designs of the Month
7-17 Amplifiers, Controllers, & Data Systems
18-22 Detectors
23-25 Numbers Machines
26-30 Recorders, Indicators, & Analyzers
31-34 Valves in Control
35-44 Power Sources
45-48 Relays & Switches
49-63 Control Components
64-66 Potentiometers in Control

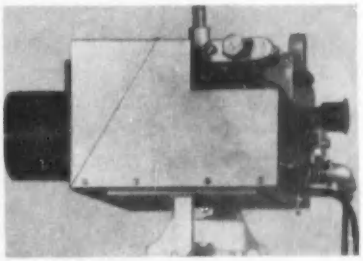


TEMPERATURE DETECTOR
temperature differentials indicated by brilliantly colored image

Were this page printed in full color the photo above would appear in a variety of bright pastel hues. The tires of the auto would be a bright yellow, the background a yellow-green, and the rest of the car various shades of blue and red. This is because the picture is the output of a unique device called the Evaporograph. It creates images according to temperature differentials, and indicates the differentials by means of brilliant colors. In the photo above, the tires and radiator are hot. Sensitive to about 2 deg F, the Evaporograph works remarkably well in total darkness, "taking pictures" of objects which, for all practical purposes, are at ambient temperature. It can do this because differences in surface reflectivity result in more or less heat radiation, and hence detection by the instrument.

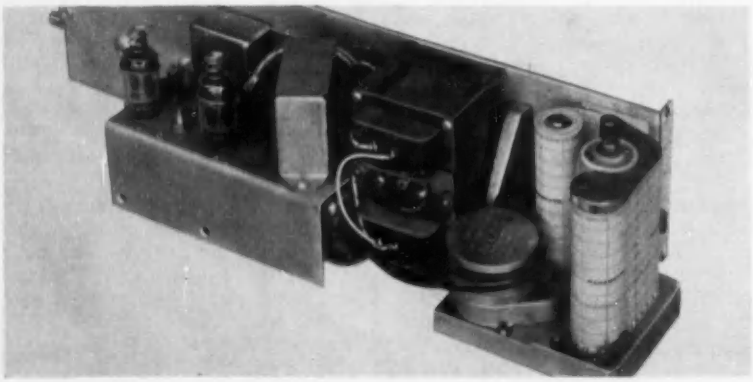
Originally developed for the military, the Evaporograph is now being offered at a price near $10,000 for applications requiring the precise detection of temperature distribution. Wind tunnel observation of aircraft surface temperatures is one application. Another is observation of temperature distribution through large vessels and complex structures. It can be used to observe heat flow through large masses, or hot spots in complex electronic assemblies. The resolution of the image is the equivalent of 30,000 individual thermocouples.

The intriguing color effects produced by the Evaporograph are created by the same color filtering properties of a thin layer of oil on water. In the Evaporograph, a thin layer of oil is evaporated on a thin carbon black-backed membrane and the image



(focused by a concave mirror and salt lens) appears as the result of different evaporation rates proportional to reflected infrared. The chamber is heated for a few seconds to evaporate the oil; as it cools, the image swims into view, changing colors as it develops. A built-in camera photographs the picture without disturbing the operator's view. It takes about 20 sec for the image to appear. *Baird Associates, Inc. 33 University Rd., Cambridge 38, Mass.*

Circle No. 1 on reply card



MULTI-VOLTMETER
pen drive uses force-feedback

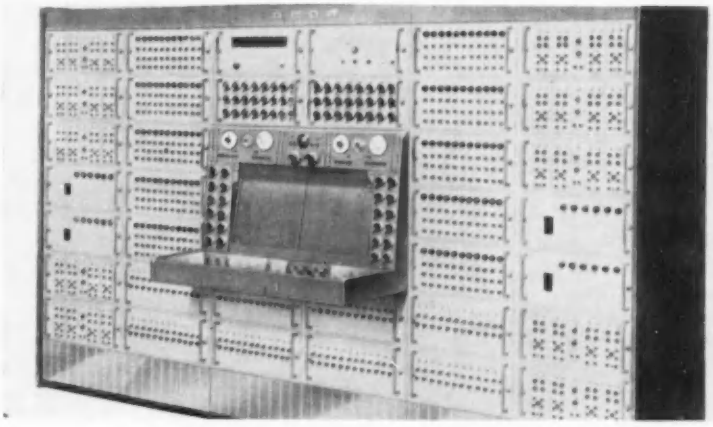
A pen-moving mechanism said to be 50,000 times more powerful than that used in conventional direct-deflection recorders directly operates alarm contacts without increasing indicating error. The chart paper is a 3-in.-wide strip or IBM card type with straight-line coordinates. The series 130 Electronic recorder's range is from 0 to 200 microamps and 0 to 20 millivolts with an accuracy of ½ per cent of range. The recorder uses an electromechanical transducer and amplifier to com-

pare the position of the pen and the input signal by means of force feedback through a spring. It takes ½ sec for ⅔ response. This speed can be upped to 0.2 sec on special order, or decreased by a factor of 4 to filter out high-speed fluctuations. It can be supplied with either high contacts, low contacts, or both. *Industrial Controls Div. of Manning Maxwell & Moore, Inc., Stratford, Conn.*

Circle No. 2 on reply card

ANALOG COMPUTER

contains up to 96 amplifiers and 50 nonlinear elements



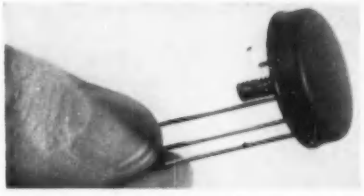
Somewhat on the massive side is this new Gedna computer, called the A14. It can operate as two independent smaller systems, or be added to for any-size problem.

The nonlinear elements include high accuracy electronic multipliers, precision electronic resolvers, stabilized electronic map readers for functions of two variables, and variable delay transport lag simulators. Also included are automatic dialing systems for monitoring operations, temperature-controlled ovens, and built-in recording channels. Goodyear's analog line now includes R5 recorder and a number of plug-in components, the latest being a noise generator and dual servo multiplier. *Goodyear Aircraft Corp., Akron 15, Ohio.*

Circle No. 3 on reply card

SEMICONDUCTOR SHOWING

seven new items court computers, servos, and power supplies



A wholly new type of semiconductor, a silicon double-based diode acts as a microsecond switch having a regenerative switching action between two stable states. Hence, it is proffered for duty in multivibrations, phase or amplitude detectors, sawtooth generators, and electric switch.

The double-based diode is among seven new GE entries in the transistor market. Others include a ¼-watt high frequency NPN silicon transistor, the ZJ 12, offering 15-db power gain at 2 megacycles. A germanium NPN the ZJ-13 is rated at a minimum of 12 db power gain at 5 megacycles. Aimed at the miniature servo market is a power PNP alloy junction silicon, the ZJ 16, shown at left, which will toss off 8 watts at 85 deg C.

Also in the offering is a 50-amp-at-200-volt silicon rectifier, compared with its selenium counterpart in the right-hand photo. For electronic

power supplies GE offers the 250-ma-at-200-volt ZJ 18. *General Electric Co., Electronics Park, Syracuse, N. Y.*

Circle No. 4 on reply card

DATA HANDLER

routes up to 1,000 voltages into digital data with unique pinboard function control

A new industrial data reduction system converts up to 1,000 transducer voltages into punched tape, cards, or automatic typewriter copy. It's offered for either process or aircraft applications. When gathering fast-changing data, readout can be at 1,500 points per sec; while when working with low-speed data read out electromechanically, it notes up to 300 points per min —a speed in line with process plant requirements.

A miniature pinboard enables special groupings, and is said to replace the zero-setting pots common to most data-handling systems. By means of the pinboard an operator can alter

Here's The "Inside Story" of

PENBERTHY GAGE VALVE SUPERIORITY

• Unmatched quality and design mean top performance at lowest cost during long service. FLOATING SHANK alone saves 50% or more on installation costs. Order through local supplier or direct. Write for Catalog No. 35 showing complete line.

PENBERTHY INJECTOR COMPANY
Division of the Buffalo-Eclipse Corporation
1242 Holden Ave., Detroit 2, Michigan

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- EJECTORS
- EDUCTORS
- EXHAUSTERS
- SYPHONS
- ELECTRIC SUMP PUMPS
- CYCLING JET PUMPS
- INJECTORS

NEW PRODUCTS

such divergent functions as scaling, zero offset, linearization, alarm limits, totalizing, and readout form. Furthermore, these operations can be performed on all 1,000 points.

The data reducer is said to make analog-to-digital conversions with an accuracy of $\frac{1}{10}$ of one per cent, with continuous checking against a standard cell. The system scans five channels per sec for punched tape readout, one channel per sec for cards or log sheet display. *Beckman Div. of Beckman Instruments, Inc., Fullerton, Calif.*

Circle No. 5 on reply card

DATA HANDLER

takes 18 channels simultaneously for 180 points sec scanning

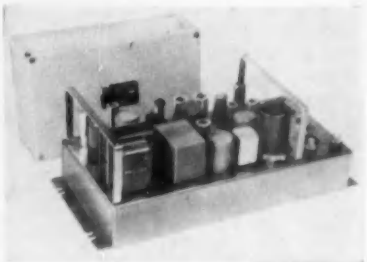
Magnetic tape, then IBM cards, take note of the voltages on 18 channels in ¼ microsec in the new Datrac C System. All 18 channels in the simultaneous conversion are noted on a single tape block and printed out on a single IBM card. Recording can be continuous if desired. Up to 750,000 individual readings can be stored on a single 10½-in. reel of magnetic tape. Relative accuracy is given at 0.025 per cent, absolute accuracy at 0.1 per cent. Inputs can have full scales of plus or minus 10 mv to 1,000 volts. The apparatus makes extensive use of magnetic circuits and standard cell internal reference, and checks the accuracy of the data as it is being transferred from magnetic tape to punched cards. Tape coding includes sign of the input and its value to four decimal digits with parity check and sprocket pulse. *Epsco, Inc., 588 Commonwealth Avenue, Boston 15, Mass.*

Circle No. 6 on reply card

AMPLIFIERS, CONTROLLERS, DATA SYSTEMS

TELEMETERING PAIR:

Given a transducer, a new pair of products will make an fm telemetering link. A millivolt dc input serves to frequency-modulate an audio tone. The receiver converts this fm signal into something that can drive a recorder. At least 45 individual channels can be accommodated between 765 to 20 kc by the setup. *Radio Frequency Laboratories, Inc., Powerville Rd., Boonton, N. J.*



Circle No. 7 on reply card

Design Factors in Telemetering Systems

Four important points to consider in planning for remote measurement or recording

A BRISTOL APPLICATION NOTE

Telemetering systems provide a proven way to keep tabs on a remotely located process, pipe line, service or utility. In fact, any time remote indication recording, or control is required, telemetering can serve your needs.

Here are the four conditions which must be considered in selecting the best telemetering system for any installation.

1. VARIABLES

Most industrial variables can now be measured, computed, and converted into a form that can be transmitted electrically. Their number and variety influence circuit complexity and the appearance of the receiving panel. Some variables now being successfully telemetered include:

Pressure • Current and voltage • Temperature • Flow • Electrical power • Wind velocity • Liquid level • Motion • BTU's • pH Horsepower • Speed

2. FREQUENCY OF READING

While the majority of telemeter systems in service today are the point-to-point continuous recording type, complex networks and interrelated variables are making sophisticated approaches more and more necessary. The problem usually boils down to these questions: how often is measurement necessary, and what is the least costly way to install and run the system?

Five types of possible hook-ups are:

Continuous recording—where variables are critical and need constant watch.

Intermittent indicating—where variables need only be checked at intervals.

Continuous-Intermittent—where it is possible to separate more critical variables for constant and intermittent telemetering.

Grouped-Multiplex—where several measurements can be transmitted as a group over a single circuit into a "multiplexed" receiver.

Successive-Multiplex—where measuring points over a large area can be "multiplexed" at intermediate locations, then herded to the panel.

3. TERRAIN

The type of interconnecting circuit between the measuring transmitters and central panel usually depends on the terrain: its topography, weather, and degree of settlement. Hence, signals may be carried by one, or by combinations, of the basic transmission media:

Radio—various types of radio can be used to take signals over mountains, deserts, and seas.

Wire—strung wire or leased lines can cover plant, urban, and rural areas.

4. INSTRUMENTATION

Bristol Metameter® Telemeters are eminently adapted to any of the conditions of measurement frequency, variables, or terrain likely to be encountered in telemetering. Transmission can be provided over telephone circuits, carrier current, radio—including microwave, VHF and UHF—and private wires, multiplexing and selective calling. Under all sorts of conditions, thousands of installations, ranging from just a few to hundreds of instruments each, have proven the dependability and reliability of Bristol Telemeters—pulse width (or duration), differential transformer, and voltage types, as well as pneumatic systems.

For more information on how Bristol Telemeters can benefit *you*, write THE BRISTOL COMPANY, 101 Bristol Road, Waterbury 20, Conn. 5.44

TYPICAL RECEIVING CENTER in multiplexed telemetering system.

BRISTOL *POINTS THE WAY IN HUMAN-ENGINEERED INSTRUMENTATION*

AUTOMATIC CONTROLLING, RECORDING AND TELEMETERING INSTRUMENTS

KEARFOTT R 900 SERIES SYNCHROS

for immediate delivery

These SYNCHROS are mass produced in a plant devoted exclusively to their manufacture. This makes the following advantages possible:

HIGH ACCURACY
Probable error 7 mins.
Maximum error 10 mins.

HIGH AND LOW TEMPERATURE STABILITY
Rugged construction minimizes null shift with temperature variations.

CORROSION RESISTANCE
Stainless steel housings, shafts, bearings and laminations.

LOW PRICES:

TYPE	MODEL	PRICE*
Transmitter	R5911-1A	$29.50
Control Transformer	R5901-1A	29.50
Repeater	R5921-1A	31.50
Differential	R5941-1A	51.00
Resolver	R5931-1A	44.00

*Based on 1-25 unit price with leads and standard shaft. Quantity prices on request.

LET US KNOW YOUR DELIVERY REQUIREMENTS — WRITE TODAY

KEARFOTT COMPONENTS INCLUDE:

Gyros, Servo Motors, Synchros, Servo and Magnetic Amplifiers, Tachometer Generators, Hermetic Rotary Seals, Aircraft Navigational Systems and other high accuracy mechanical, electrical and electronic components.

Send for bulletin giving data of components of interest to you.

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KEARFOTT COMPANY, INC., LITTLE FALLS, N. J.

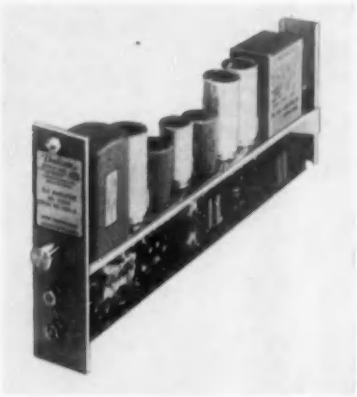
Sales and Engineering Offices: 1378 Main Avenue, Clifton, N. J.
Midwest Office: 188 W. Randolph Street, Chicago, Ill. South Central Office: 6115 Denton Drive, Dallas, Texas
West Coast Office: 253 N. Vinedo Avenue, Pasadena, Calif.

NEW PRODUCTS

NOISE MAKER:

Intended for testing ratemeter and radiation detection circuits, a little 6-lb random noise generator operates from either line current or flashlight cells. *Universal Atomics Corp., 19 E. 48th St., New York 17, N. Y.*

Circle No. 8 on reply card



DC AMPLIFIER:

A plug-in amplifier, Model C23125, **uses a magnetic converter in its input stage in place of the common electromechanical chopper.** This innovation isolates the millivolt input signal from the rest of the circuit. Among its characteristics:

- gain of 5,000
- linearity to within 0.1 per cent
- drift less than 30 microvolts
- rise time less than 0.05 sec
- noise less than 20 microvolts as referred to input.

The magnetic converter uses a 400-cps, 6.3-volt input. *Doelcam Div. of Minneapolis-Honeywell, 1400 Soldiers Field Road, Boston 35, Mass.*

Circle No. 9 on reply card

DT CONTROLLER:

A new pickup controller offers low, medium, and high frequencies from 1 to 20 volts **for the excitation of two independent differential transformer pickups.** Adjustable amplifiers have meter outputs for each channel. Overall stabilization against line changes is within 0.25 per cent. *Crescent Engineering & Research Co., 11632 McBean St., El Monte, Calif.*

Circle No. 10 on reply card

SPEED CONTROL:

A new electronic control developed specifically for the control of machine tool spindle speeds uses two full-wave

MEMO

TO Engineering Dept.

SUBJECT

MINIATURE SENSITIVE RELAY (TYPE MS)

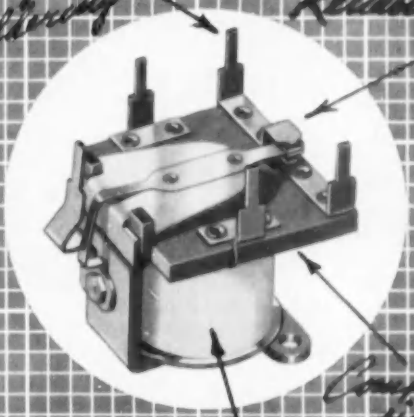
(IDEAL FOR PRINTED CIRCUITS)

Note desired RBM features will cut Our Assembly Costs

Mgr.

Self locking Terminals position Relay before soldering

X-Bar Contacts insure ultimate in Circuit Switching Reliability



Compact size

Coil Construction meets severest climatic conditions

Construction—Printed circuit terminals are designed with snap-in feature which holds relay in printed circuit board without lugging prior to solder dip.

Other versions of MS relay available with standard solder type terminals and insulating base, where required. Also with 4 N.O. isolated circuits having common make.

While not yet in production, extra-sensitive version has been developed. Maximum coil resistance 18,000 ohms, nominal sensitivity .030 watt, maximum sensitivity .020 watt, overall height 1-9/16". All other details same as standard MS relay.

Application—Type MS is an ideal relay for any application requiring a compact, highly reliable single pole D. C. device, where a low cost solution is required because of volume usage and competitive problems.

The fact that industry has already used over a million units of this design is your assurance that the R-B-M Type MS relay will meet your most exacting requirements.

Contacts used in Type MS are of the cross bar type, which offer the ultimate in reliability throughout the life of the relay. Molded bobbin design has eliminated coil failure on sensitive applications under severe climatic conditions.

OTHER VERSIONS

SOLDER TERMINALS
4 isolated circuits with common make contact.

INSULATED BASE
Solder terminals mounted on insulating base.

EXTRA SENSITIVE VERSION

ENGINEERING DATA	
Specifications	Miniature Sensitive Relay Type MS
Contact Form	S. P. D. T.
Contact Rating	1 amp. 32 V.D.C. non-inductive
Coil Resistance	Up to 10,000 ohms
Nominal Sensitivity (Coil Input)	.060 Watt
Maximum Sensitivity	.040 Watt
Approx. Dimensions	1⅛ x 1⅛ x 1½"

CORD SETS
WIRE HARNESSES
MAGNET WIRE
OTHER PRODUCTS

Send for Descriptive Bulletin MS-1

RBM DIVISION

ESSEX WIRE CORPORATION, *Logansport, Indiana*

Now *simpler, more accurate control of oxygen in*

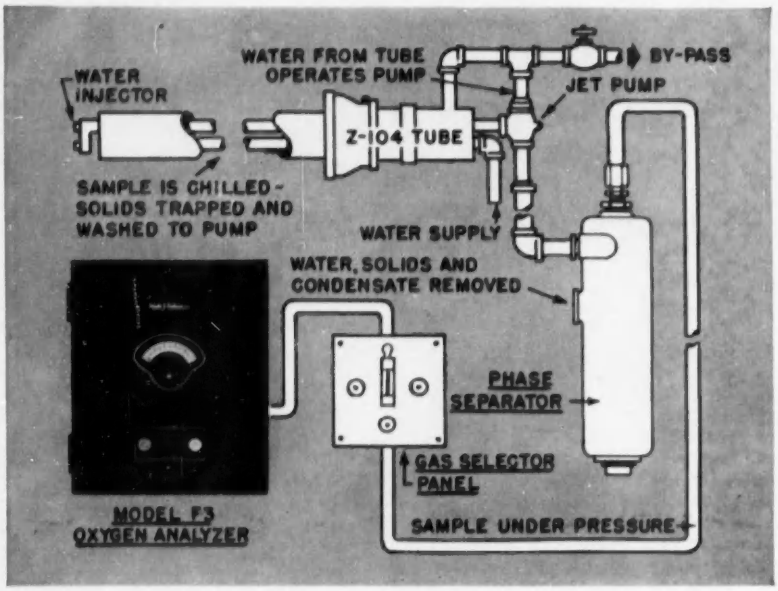
BOILERS...FURNACES...KILNS...DIRECT-FIRED HEATERS, ETC.

with Arnold O. Beckman INC.

complete Analysis Systems!

Arnold O. Beckman, Inc. – leaders in developing advanced instrumentation for accurate oxygen control – now offers *complete* analysis systems for higher combustion efficiencies at lower fuel costs.

These field-proven systems are already being used by progressive operators to boost profits, cut costs – and they will make the same savings for *you*. They consist of Analyzer, and Sampling System – all in one compact installation suitable for indoor or outdoor location. For severe temperature conditions, heated cabinets can be supplied.



The diagram (above) shows a typical analysis system for boilers. The incoming sample gas is first chilled and washed . . . then passes through a Separator where the condensables and solids are removed. The resulting clean, dry sample gas flows under pressure to the Gas Selector Panel (for selecting "Zero," "Span" and "Sample" gases) . . . then into the Analyzer where the oxygen content is quickly measured. The Analyzer may be used with any standard recorder or controller.

Result – new speed, simplicity and accuracy in controlling air-fuel ratios, with important savings in fuel and operating costs!

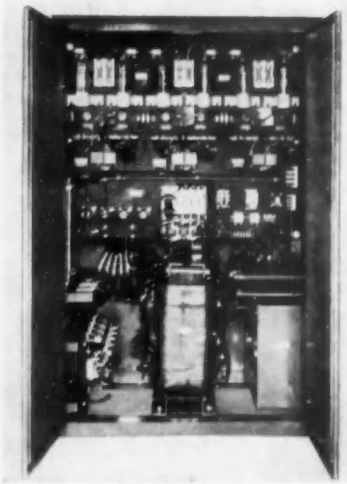
Get the full story on these Complete Analysis Systems by writing for Data File # 19V-46.

Arnold O. Beckman INC.
ANALYZERS
Profit Builders for Industry
1020 Mission Street
South Pasadena, California

NEW PRODUCTS

thyratron rectifiers, one for the motor's field, the other for armature service. Rpm sensing is accomplished by detecting the voltage drop across the respective coils. *Federal Pacific Electric Co., 50 Paris St., Newark, N. J.*

Circle No. 11 on reply card



MOTOR DRIVE:

A new thyratron dc motor power supply offers a speed range of 10 to 1 for **10 to 50 hp drives.** The armature current can be adjusted from 100 per cent to 200 per cent of full load. Speed regulation is maintained within about 10 per cent. A reversing switch and dynamic braking arrangement are also included. It can be operated by three-wire remote control. *The Electric Works, Dept. CLN, 17 S. Jefferson St., Chicago 6, Ill.*

Circle No. 12 on reply card

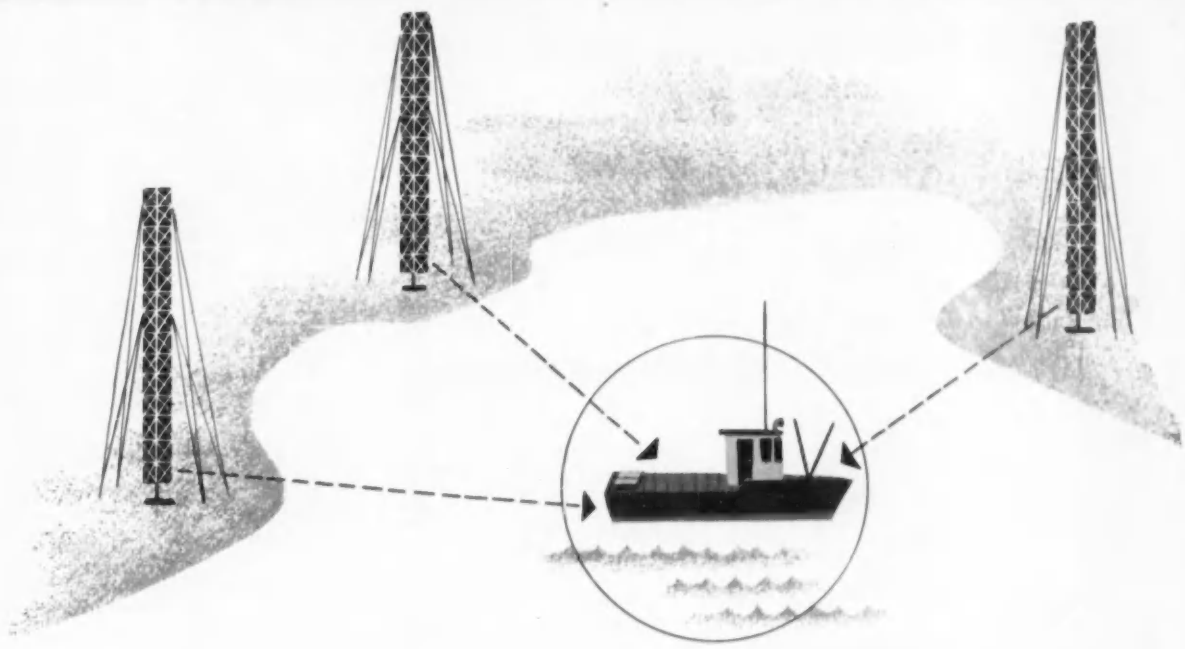
DECOMMUTATOR:

The circuits required to demodulate, and independently adjust gain and zero level, and monitor **30 telemetered channels within 0.5 per cent** are contained in a single rack. The system handles both fm/fm and pwm data. *The Ralph M. Parsons Co., 135 W. Dayton St., Pasadena, Calif.*

Circle No. 13 on reply card

LOAD CONTROLLER:

The "Loadtrol" operates motors used in mechanical parallel (such as in powering conveyors, pumps on a single line, etc.) **to provide operation according to load.** That is, if two motors are needed to operate a conveyor under maximum load, this de-



how Transicoil servos help LORAC

bring off-shore navigation to accuracies within yards

LORAC (LOng Range ACcuracy), one of the newest methods of close tolerance navigation, is now providing pin-point positioning for ships at sea, well away from land or other navigational markers. Developed by the Seismograph Service Corporation, this novel system compares the phase relationship of three sets of radio signals to fix position.

Lorac accuracy depends on the ship's receiver having laboratory type dependability and precision under extreme corrosive atmosphere and rough handling. Yet the servo phase resolver and indicator can spot position to within a matter of yards.

This all-important servo indicator-package was designed and built by Transicoil to meet the specific requirements of shipboard use.

When coupled to the electronic section of the receiver, this unit continuously measures the phases of the incoming signals by comparing the phase of the beat frequency with a modulated reference signal, and presents the position information on the counter-pointer type dial face.

The Transicoil servo assembly used in the Lorac receiver. Components include a 400 cycle oscillator supply for two indicators and two servo amplifiers. System is built on separate chassis to permit the indicators and amplifiers to be located in separate parts of the ship.

The Lorac system is typical of the way in which Transicoil can solve your servo problems to bring new measures of accuracy and dependability. Transicoil will develop and manufacture a complete "package" servo system to conform to your individual requirements. You pay only for results—on a fixed fee basis for equipment delivered and functioning properly.

Write today for further information, outlining your servo problem.

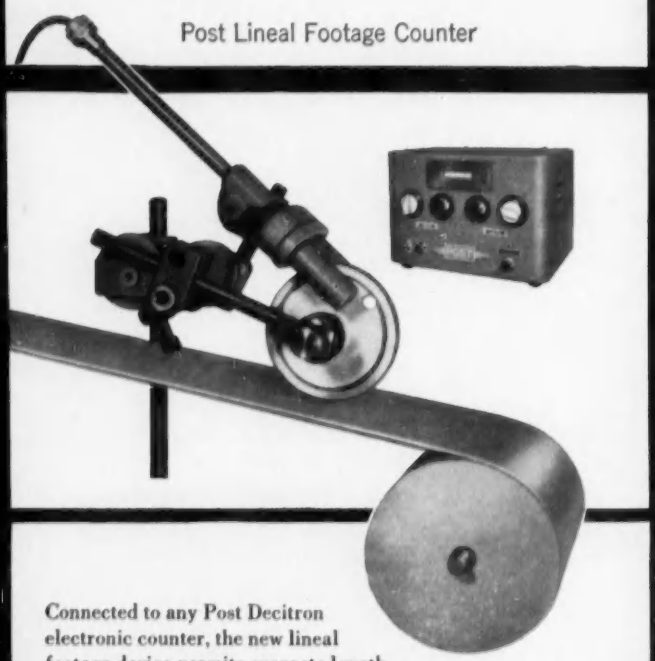
TRANSICOIL CORPORATION

Worcester, Montgomery County · Pennsylvania

COUNTS to any length

accurately — easily!

Post Lineal Footage Counter

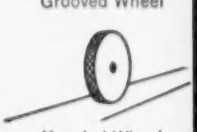


Connected to any Post Decitron electronic counter, the new lineal footage device permits accurate length measurement for continuous production items.

Each time the wheel revolves a photolight beam is broken and a count equal to one foot is registered by the counter. Varied "beam-hole", or wheel size will permit the counting of fractional parts of a lineal foot if desired. Different types of wheels provide traction surfaces for wire, rope, aluminum sheets, bar or flat steel, paper, cloth, etc.

Used in conjunction with a Post Decitron "preset" counter, (i.e. PW-2) a predetermined length of stock can be measured, and "marked" or cut-off as desired.

Grooved Wheel



Knurled Wheel

Rubber Coated Wheel

Rely on Decitron . . .
for Counting Measurement and Control

POST

Electronic Products Division
Dept. 552

POST MACHINERY CO.
Beverly, Mass.

NEW PRODUCTS

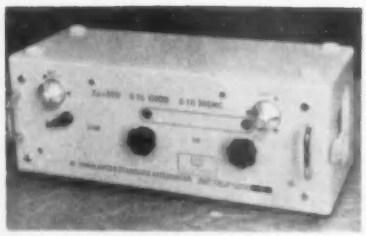
vice will cut one of them off during light load conditions when one motor will do the job. It gets its control information from the current drain of one of the motors, operating the other when the demand goes above a set point. The controller can be used to operate solenoids or valves during high-load conditions too. *Reitz Mfg. Co., Santa Rosa, Calif.*

Circle No. 14 on reply card

IMPROVED AMPLIFIER:

Progress, progress. It was only in December of 1955 that the first version of a new servo amplifier appeared—a compact plug-in thing with chopper input stage—and now, barely a few months later, **the voltage gain is improved 100 times!** What comes out is now 25,000 higher than what goes in. *Servo Corp. of America, 2020 Jericho Turnpike, New Hyde Park, L. I., N. Y.*

Circle No. 15 on reply card



STANDARD ATTENUATOR:

Imported from Germany is a new adjustable attenuator that passes dc to 30 mc with **attenuation from 0 to 100 db in 1-db steps.** Its characteristic impedance is 50 ohms. *Federal Telephone & Radio Co., 100 Kingsland Road, Clifton, N. J.*

Circle No. 16 on reply card

THYRATRON CONTROL:

Proportional control of 60-cycle single-phase half- or full-wave thyratron **kilowatt outputs from control signals less than 1 milliwatt** can be achieved through a compact magnetic circuit. It works by shifting phases as much as 300 deg with linear shift to 180 deg for proportional control. High sensitivity models operate from thermocouple outputs. Four isolated dc inputs enable action according to separate signal source variations. *Vectrol Engineering, Inc., P. O. Box 1089, Stamford, Conn.*

Circle No. 17 on reply card

Which one of these Genisco Accelerometers meets your guidance system requirements?

Model GMO—A small, rugged instrument with relatively high natural frequency. ±2G to ±30G ranges.

Model GLH—Thousands produced. Magnetically damped. Excellent dynamic characteristics over MIL temperature range. ±2G to ±30G ranges.

Model GOH—Heated-oil damping. A rugged instrument, useful in severe vibrational environments. ±1G to ±3G ranges.

Model GLO—Like Model GLH, in aircraft case. Caging and dual output available. Ranges as low as ±½G. Can supply oil-filled case for low vibration excitation.

Model GMH—Small, heated-oil damping. High natural frequency. Excellent performance in severe vibrational environments. ±1G to ±30G ranges.

Now in large scale production

Genisco Accelerometers are potentiometer-type instruments. Unique design features, plus unusual skill in potentiometer manufacture, result in extremely low noise levels. Several instruments are now in use on missiles in large scale production.

Your particular requirements will receive careful attention. Write today, outlining your needs. Genisco Incorporated, 2233 Federal Avenue, Los Angeles 64, California.

Genisco INCORPORATED

RELIABILITY FIRST

Engineered for

tomorrow's needs...today...

NORDEN-KETAY OFFERS YOU DIRECT ANALOG-TO-DIGITAL CONVERSION WITHOUT TRANSFORMATION

Combining accuracy with compact design, Norden-Ketay's ADC-1A family of Analog-To-Digital Converters provides you with *unambiguous natural binary output*. All digits are available nearly simultaneously...allowing a high reading rate and may be read while the shaft is in motion. Both the binary number and its complement are available, simultaneously.

RAPID READOUT—up to 10^6 per second.

PARALLEL READOUT—greatly simplifies external circuitry.

COMPACT DESIGN—engineered for minimum size and weight.

INPUT—DC or pulse voltages.

LOW TORQUE—less than 0.2 inch ounces to turn input shaft.

LOW INERTIA—approximately 9 gram centimeters^2.

CLOCKWISE OR COUNTER CLOCKWISE OPERATION—either is possible by selection of appropriate output leads.

AVAILABLE IN ANY CAPACITY TO 19 DIGITS—other capacities available on special order.

For full details write for File #084.

NORDEN-KETAY CORPORATION

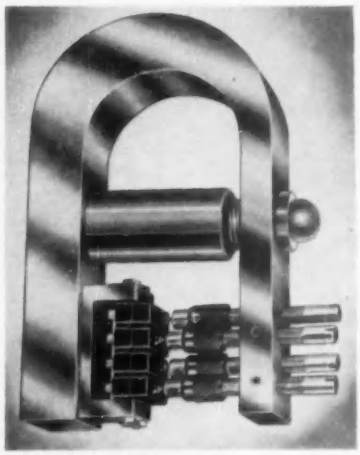
INSTRUMENT AND SYSTEMS DIVISION

Wiley Street, Milford, Connecticut

INDICATING PRECISION PRESSURE GAGES • REMOTE INDICATING DEVICES • ANALOG DIGITAL CONVERTERS • FORCE BALANCE PRESSURE TRANSDUCERS • ELECTROMECHANICAL CONTROL SYSTEMS • AIRBORNE RADAR • SHIPBOARD LINE CONTROL EQUIPMENT AIRCRAFT FUEL FLOW INSTRUMENTATION • ACCELEROMETERS

NEW PRODUCTS

DETECTORS



FORCE SENSORS:

As many as four snap-action switches are operated by loads detected through this transducer. Each of the **switches can be separately adjusted for operation at a different load point,** or the adjustments can be factory-sealed. Accidental overloads are transmitted through a solid rod, preventing excessive deflection of the gage. Eleven ranges handle loads from 0 to 25 lb all the way to 0 to 50,000 lb. The model shown is for compressive loads, although tensile sensors are also available. *W. C. Dillon & Co., Inc., 14620 Keswick St., Van Nuys, Calif.*

Circle No. 18 on reply card

PART DETECTOR:

Operating on principles similar to that of modern mine detectors, a new parts pickup detects metallic (magnetic or nonmagetic) materials falling from or into chutes or containers. Used with a companion power supply and oscillator, the setup **produces a dc signal for the operation of counters or actuators.** The sensing coils are available

in 15 sizes ranging from ¼ to 3 in. ID. Sensing rate is up to 12,000 items per min. *Electro Products Laboratories, 4500 N. Ravenswood Avenue, Chicago 40, Ill.*

Circle No. 19 on reply card

DT DYNAMOMETER:

The beam-type dynamometer shown here ties in with standard vacuum tube voltmeters, oscillographs, or recorders **for indicating forces of from 0 to 10 grams up to 0 to 50 lb.** It uses a linear differential transformer having a full-scale output of 0.250 volts with a 6.3-volt 60-cps input. *Schaevitz Engineering, P. O. Box 505, Camden 1, New Jersey.*

Circle No. 20 on reply card

THERMAL SWITCH:

A new waterproof thermal switch about the size of a stove match **has an operating differential of only 1 deg** and a range of from minus 20 to plus 1,000 deg F. Contact rating is 1¼ amps at 28 vdc. *Control Products, Inc., 306 Sussex St., Harrison, N. J.*

Circle No. 21 on reply card

RUNNING TORQUE METER:

Accurate speed indication to within 1 per cent for rpm's to 10,000 and **torques from ¼ to 320 in.-oz** are features of the Type 300 Running Torque Testers and Dynamometers. Three different models handle torque sources up to ¾ hp. *John Chatillon & Sons, 85 Cliff St., New York 38, N. Y.*

Circle No. 22 on reply card

Here's what you've been looking for...

A GEAR HEAD SERVO MOTOR WITH LOW INERTIA...LOW BACKLASH AND A BIG PLUS IN FLEXIBILITY!

Norden-Ketay engineers design quality precision components that meet all your requirements. By combining low inertia and low backlash with new flexibility in servo motor design, Norden-Ketay makes possible...

MAXIMUM GEAR RATIO VARIATIONS—from 5:1 to 10,000:1 by simply changing gear clusters.

MAXIMUM BACKLASH CONTROL—backlash restricted to less than 0° 30'.

MAXIMUM OUTPUT TORQUE—from 50 inch ounces to 150 inch ounces.

EASE OF MAINTENANCE—simplified design offers quick easy assembly and maintenance.

CORROSION RESISTANT—built to military specifications (MIL E-5272A).

AVAILABLE IN VARIOUS SIZES—11, 15, 18. Other sizes available on special order.

For complete details write for data file #084.

NORDEN-KETAY CORPORATION

PRECISION COMPONENTS DIVISION:
555 Broadway, New York 12, N. Y.
WESTERN DIVISION:
13210 Crenshaw Blvd., Gardena, California

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excellent salaries for—

DIGITAL COMPUTER ENGINEERS

who can fill key creative posts in long-range, non-military research and design

FOR ADVANCED BUSINESS COMPUTER SYSTEMS

* SENIOR ELECTRONICS ENGINEERS

To specialize in research and design for advanced business computer systems. Must have exceptional creative ability, plus knowledge of vacuum tube circuit design, transistor circuitry.

* SENIOR DIGITAL COMPUTER ENGINEERS

For projects in advanced computer design, development and application. Must have thorough knowledge of digital computer logic and circuitry, input-output devices, programming.

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For advanced research and design in computer transistor circuitry. Capabilities should include ability to direct others in new project work.

OPPORTUNITY FOR ELECTRONIC OR ELECTRICAL ENGINEERS

Background in one or more of the fields below equips you for excellent career positions with NCR Electronics Division:

LOGICAL DESIGN • FERROELECTRICS • MAGNETIC CORES • COMPUTER SYSTEMS • TRANSISTOR CIRCUITS • INPUT-OUTPUT DEVICES APPLICATIONS OF PHYSICS • COMPUTER SYSTEMS SPECS. DEF. OF SYSTEM REQUIREMENTS

"GROUND FLOOR" OPPORTUNITY WITH UNUSUAL STABILITY

Openings listed here are for the basic organization of the NCR Electronics Division. If you qualify for one of them, you'll be a key member of this fast-developing division of one of America's top companies. You'll enjoy the freedom of a small, select research group — operated *by* engineers *for* engineers — as well as the exceptional financial stability of a large, long-established firm. A full program of employee benefits, too. New, modern, air-conditioned plant with every modern research and development facility in a conveniently situated Los Angeles suburb.

* *For illustrated company brochure, write Director of Personnel.*

National*

*TRADEMARK

NATIONAL CASH REGISTER COMPANY
ELECTRONICS DIVISION *3348 West El Segundo Blvd., Hawthorne, Calif.*

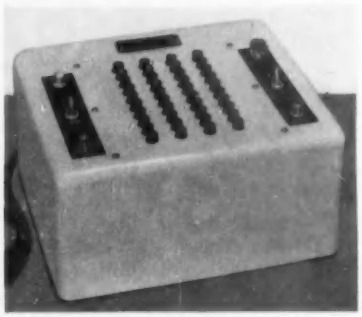
NEW PRODUCTS

NUMBERS MACHINES

COUNTER PRINTER:

Intended as a printout for electronic counters, the machine shown here **puts up to 10 digits on conventional adding machine paper.** It contains a solenoid operated adding machine, power supply, and relay matrix. *Berkeley Div. of Beckman Instruments, Inc., 2200 Wright Ave., Richmond 3, Calif.*

Circle No. 23 on reply card



DECIMAL TO BINARY:

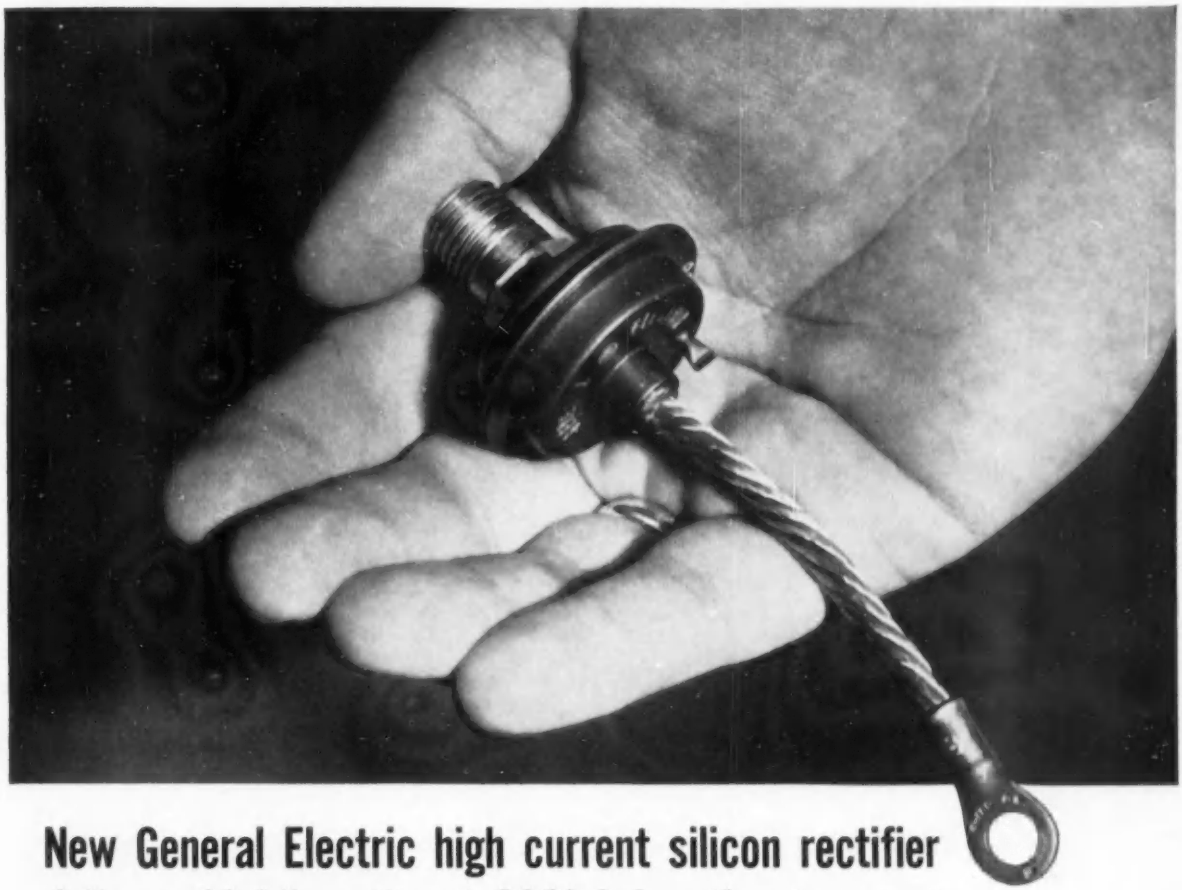
The **conversion of four-digit decimal numbers to 14 straight binary digits,** with sign, is accomplished in the neat machine shown above by means of relays. The inserted number is held until a "clear" button is pressed. *Hanson-Gorrill-Brian, Inc., 85 Hazel St., Glen Cove, N. Y.*

Circle No. 24 on reply card

DIGITAL TO ANALOG:

Up to **ten-bit binary codes are put in analog form** by a pair of new-digital-to-analog converters. Model 1050 makes 15,000 readings per sec, while model 1002 operates at up to 200,000 inputs per sec, making corrections in its output within 5 microsec. *ACF Electronics, Dept. 204, 800 N. Pitt St., Alexandria, Va.*

Circle No. 25 on reply card



New General Electric high current silicon rectifier delivers 10 kilowatts at 200° C junction temperature

The new General Electric high current silicon rectifier delivers 10 kilowatts—from a much smaller, rugged, and more compact package. It offers improved efficiency in a wide variety of applications such as jet aircraft, locomotive propulsion motors, and electro-chemical equipment.

Exclusive General Electric Design

The compact, steel package is hermetically sealed to prevent contamination. The exclusive pipe thread stud design provides best possible thermal connection to the heat sink. As a result: The new General Electric silicon rectifier offers a more efficient and reliable method for converting AC to DC for any application. A full year warranty is your assurance of fine performance.

Many Possible Applications

The new semiconductor device will prove invaluable for rectification in the new AC distribution systems of modern jet aircraft. In the locomotive industry, the unit is used to rectify the power supply for traction motors. In the electro-chemical field—for use in electrolysis and plating equipment. Other possible applications include computer power supplies and DC central station telephone power supply equipment.

Your G-E Man Has The Details

Ask your G-E Semiconductor Specialist for the full technical characteristics, ratings, and specifications together with production and delivery information. Or, write today to: *General Electric Company, Semiconductor Products, Section X9946, Electronics Park, Syracuse, New York.*

TYPICAL APPLICATION GENERAL ELECTRIC HIGH CURRENT SILICON RECTIFIER

CIRCUIT	Three Phase Bridge Rectifier, Resistive Load.
D-C OUTPUT	280 volts, 215 amperes, 60 kilowatts.
RECTIFIER LOSSES	Less than one percent (½ KW).
COOLING REQUIRED	One 6 inch square ¼" thick copper fin for each of six rectifying units when used with 2000 fpm 35°C forced air. Free convection cooling may be utilized by increasing the fin area.
VOLUME	Total volume of rectifiers and fins—less than ⅓ of a cubic foot.

Progress Is Our Most Important Product

GENERAL ELECTRIC

modernization

For the benefit of those to whom marking pulses and spacing pulses are only assorted bauds—the top illustration represents a venerable, familiar and respected telegraph relay made by one of the great corporations. For a long time it has been common in Teletype communication equipment; and, as with the DC-3 airplane, its "bugs" are pretty well domesticated.

Then, in a 1946 development contract, the Signal Corps asked for a small equivalent — hermetically sealed against the tropics and G. I. fingers. Ironically enough, when it came time to try and sell the result (Sigma Series 7 ▯) nobody had any way of using it unless it fitted existing sockets and cover clamps.

This led to the preposterous but effective arrangement in the second illustration.

There was only one trouble. It had been the custom with the predecessor relay to clean and adjust contacts at infrequent intervals during a long service life. Hermetic sealing, besides somewhat impairing contact life, makes service and adjustment quite impractical. (Some will recall previous mention of the Air Force Captain and his dramatic "small hole treatment." The story was true.) So the verdict on the Series 7 was confused: Good in "tactical" situations; i. e., foxholes; also good in some commercial equipment, but n. g. in other.

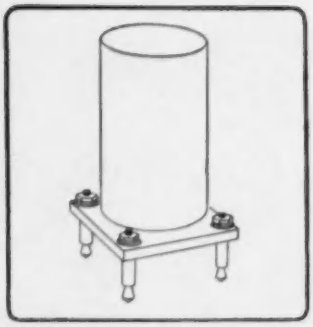
A private attempt to end all such attempts — with a *good* Sigma telegraph relay once and for all — led to the Series 72 ▯. In order to be sure of *no* distortion at 100 word-per-minute speeds, it was made capable of acceptable behavior at 1000 w.p.m. Not only was it made with a detachable cover, but the wearing parts were made replaceable like phonograph needles. (It was our good fortune that the "72" turned out, in addition, to be a rather decent relay on a great many other counts, which means business outside the telegraph field.)

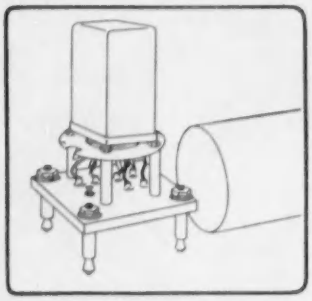
Now, of course, there may be some devil-may-care individuals actually designing future equipment of this type with octal sockets. The AB-37 Adaptor is still around, however, for those who must look before they leap.

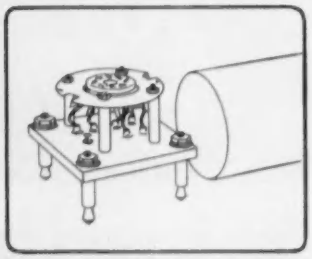
SERIES 72
HIGH SPEED
RELAY

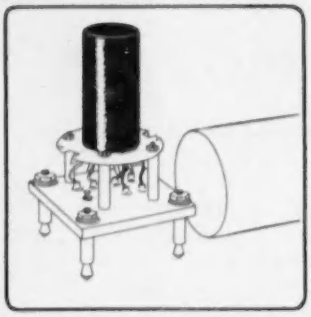
Outstanding Specifications

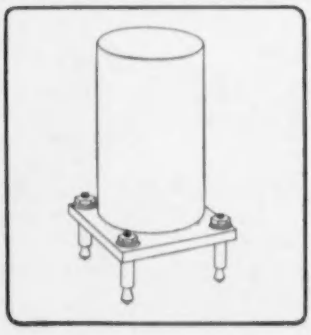
Pulse Relaying	500 per second at 75% efficiency
Life under Load	About 500 million operations without adjustment. (110 V 60 ma. DC simulated printer)
Maintenance	Bias, Sensitivity adjustable; contacts, armature easily replaceable
Vibration Immunity	15 g to 500 cps even unenergized









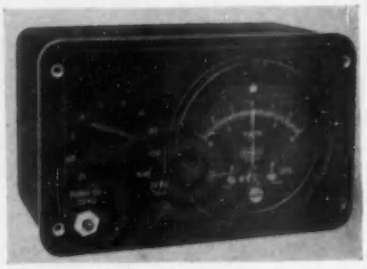


SIGMA

SIGMA INSTRUMENTS, INC., 69 Pearl Street, So. Braintree, Boston 85, Massachusetts

NEW PRODUCTS

RECORDERS, INDICATORS, & ANALYZERS



MILLIVOLTMETER:

Small enough to be built into equipment panels, the little VTVM shown here responds **full scale to as little as 500 microvolts.** A unique chopper amplifier results in accuracy to within 2 per cent. Input impedance is 5 megohms. *Trio Laboratories, Inc., 3293 Seaford Ave., Wantagh, L. I., N. Y.*

Circle No. 26 on reply card

OSCILLOGRAPH:

A bandwidth of the 900 cps is leading feature of a new direct-writing multichannel oscillograph. **It has eight channels,** including a marker channel, and a chart speed of from 1 to 16 cm per sec. Each galvanometer requires a peak input of 75 volts at 10 ma. An available amplifier will provide this output for a 1-volt signal

G-M Servo Motors
GUARANTEED
TO MEET ALL MIL. ENVIRONMENTAL SPECIFICATIONS

By specializing in servo motors only—not systems—G-M gives you these advantages...

- A broader line of servo motors in sizes and types to meet a wide range of applications.
- Servo motors available in *all* the standard sizes.
- Standard sizes specially modified to meet specific circuit requirements—available on a quick-service basis.
- Creative engineering in designing special motors with special characteristics.
- Faster production—better service.

When reliability under extreme conditions is essential—specify G-M Servo Motors! G-M has long specialized in supplying precision servo motors to the Military Avionic Industry, especially designed to meet military specifications for humidity, salt spray, temperature, vibration and altitude. Whatever your needs, let G-M build a servo motor with the *right* characteristics to perform to your specifications.

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Motor Generators
Synchronous-Hysteresis Motors

Write *today for G-M charts, specifications, or consultation.*

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G-M Servo Motors

manufactured by the Components Division of

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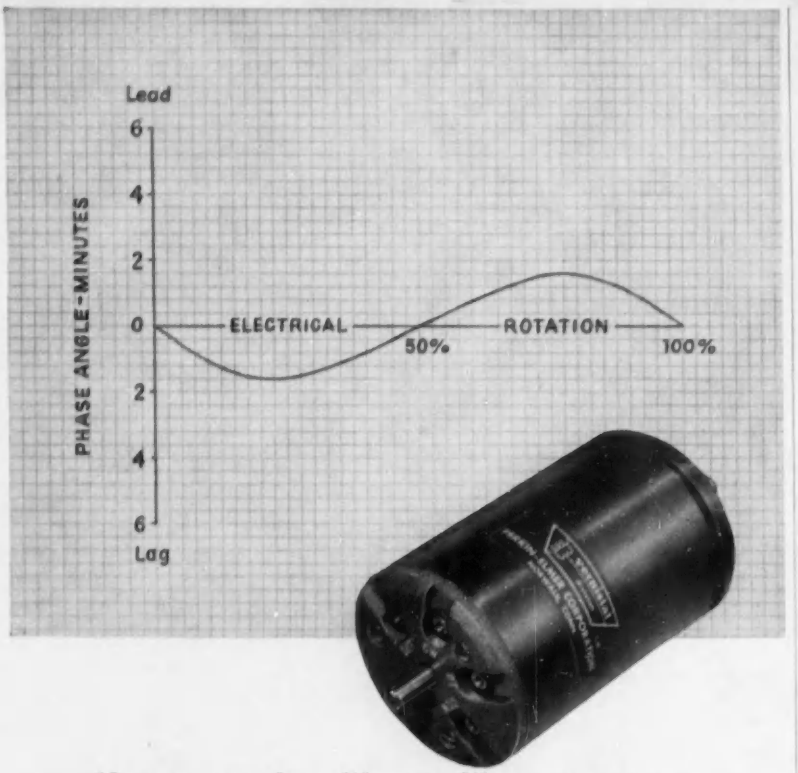


if you work with position servos...

HERE'S HOW TO LICK QUADRATURE

with the **vernistat*** a.c. potentiometer

If you work with position servos, you have had problems with quadrature. The tighter the servo loop, the more serious unwanted voltage due to phase shift can be.

Quadrature problems are tremendously simplified and more accurate servos are possible when you use the Vernistat. Although it contains a transformer, the Vernistat has extremely low phase shift. Phase angle is less than 1.6 min. at 400 c.p.s. in most systems.

The Vernistat is an a.c. potentiometer that combines *high* linearity and *low* output impedance. Size and mounting dimensions are designed to the BuOrd specification for a size 18 synchro.

SPECIFICATIONS OF MODEL 2B

Linearity Tolerance	± 0.05%
Minimum Output Voltage Increment	0.01%
Electrical Rotation	3494°
Mechanical Overtravel (each end)	45° approximately
Phase Angle (at 400 c.p.s.)	1.6 minutes, maximum
Excitation Frequency	20 to 3000 c.p.s.
Output Impedance	less than 130 ohms
Input Impedance	65,000 ohms, minimum
Maximum Input Voltage	130 V. at 400 c.p.s. or 20 V. at 60 c.p.s.

*TRADEMARK

vernistat division

PERKIN-ELMER CORPORATION

Norwalk, Connecticut

NEW PRODUCTS

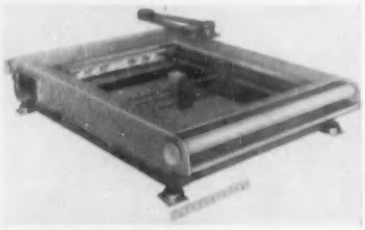
into a megohm. It marks 35 mm carbon-blacked film with a 1 mm trace. Meanwhile a visual display of the inputs appears on a ground glass, with a full-scale deflection of 5 mm per channel. *Acton Laboratories, Inc., Acton, Mass.*

Circle No. 27 on reply card

THERMAL ANALYZER

A console the size of an upright piano enables the rapid determination of thermal conductivity to within 5.0 Btu/ft² deg F/in. It's done with hot and cold surfaces. *Custom Scientific Instruments, Inc., Kearny, N. J.*

Circle No. 28 on reply card



PLOTTING BOARD:

Used as part of an aircraft automatic navigation system, the plotting board seen here takes care of a **18-by-24-in. plotting area** with an accuracy of ±½ in. Input sensitivity is 10 volts per in. at 400 cps. Speed of response is 2 to 3 in. per sec. In its application the board gets dead reckoning information from a computer which converts latitude and longitude inputs to mercator form. *Servo Corp. of America, Jericho Turnpike, New Hyde Park, N. Y.*

Circle No. 29 on reply card

ULTRAVIOLET RECORDER:

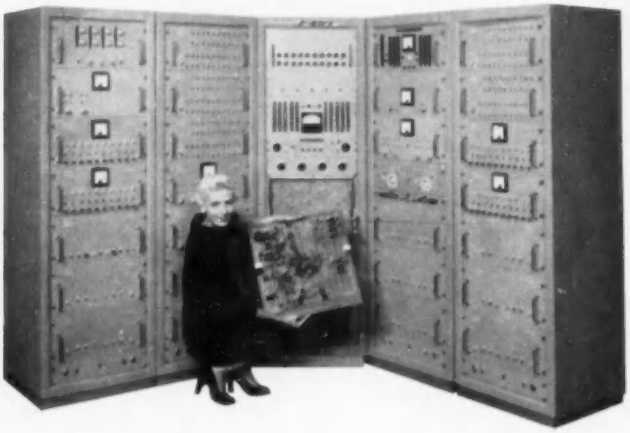
A fully automatic quantitative and qualitative analyzer provides high resolution continuous spectra on a sample within 90 sec. The instrument **records linear transmittance or linear absorbance.** Other features include a new double monochromator, continuously variable scanning speeds, and a 100 per cent line compensator. An attachment extends its range through the visible and into the near-infrared field. *The Perkin-Elmer Corp., Norwalk, Conn.*

Circle No. 30 on reply card

LARGE – includes two control units with 200 pots, 80 amplifiers, corresponding number of multipliers, function generators, etc., plus digital voltmeter with printed readout, two 4-channel recorders, timing matrix and special interconnecting panel. Price range, $100,000 to $200,000.

Whether your computer needs are small, medium or large –

You Can't Beat An EASE* For ★ FLEXIBILITY ★ CONVENIENCE ★ ACCURACY Per Dollar!



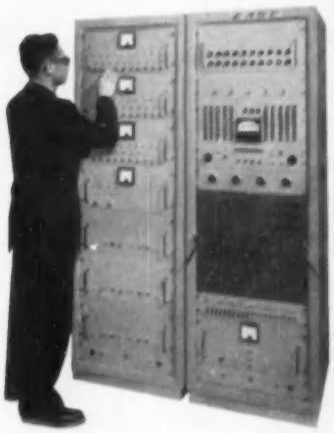
HERE'S WHY:

1. FLEXIBILITY... EASE* computers are a combination of standardized precision computer components built around the most versatile centralized control receptacle yet devised. Your EASE* computer can literally grow with the job as your requirements change or expand, with no loss of initial investment and very nominal added cost!

2. CONVENIENCE... EASE* offers centralized pushbutton control of problem solution, coefficient setting, and monitoring, plus the ultra-convenient EASE* patchboard – eliminates tedious manual pot setting, speeds set-up and solution time!

3. ACCURACY... chopper-stabilized dc amplifiers, 0.1% computing resistors and capacitors are standard, for high accuracy and stability. Servo-set coefficient pots can be set and adjusted under load to 0.01% accuracy. (If lower accuracy is permissible for your work, we can supply lower-cost units accordingly).

MEDIUM – includes control unit with 100 pots, 40 amplifiers, 14 electronic multipliers, function generator set-up unit with 1 pushbutton and 5 manual set generators, 2 servo multipliers, preset timer control unit, power supplies. Price range, $30,000 to $65,000.



SMALL – includes control unit with 50 pots, 30 amplifiers, 2 electronic multipliers, 10 initial condition voltage sources, power supplies. Price range, $12,000 to $25,000.

Want the most for your computer dollar? Investigate EASE* now! Our consulting service will supply sample solutions to your typical computer problems, recommend the type of EASE* computer best suited to your work. For complete information, please address Dept. L4.

*TM for Electronic Analog Simulation Equipment by BERKELEY

Berkeley *division*

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BECKMAN INSTRUMENTS INC.

2200 Wright Avenue • Richmond 3, Calif.

AFFILIATE OF GENERAL CERAMICS CORPORATION

Magnetic Amplifiers · INC

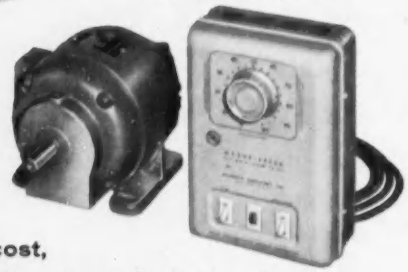
—announces its new

VARIABLE SPEED DRIVE

MAGNE-SPEED*

SIZE II — 3/4, 1 and 1-1/2 HP

SIZE I — 1/4, 1/3 and 1/2 HP



Stepless, instant starting, compact, 50:1 speed range, good regulation without tachometer, long life, virtually maintenance free service, low cost, fast response, reversibility, dynamic brake, local or remote control. Write for Bulletin S580-5-55.

Other MA Products and Services

Magnetic Servo Amplifiers
Transi-Mag * Amplifiers
Analog Computors
Photoelectric Controls
DC and AC Regulated Power Supplies

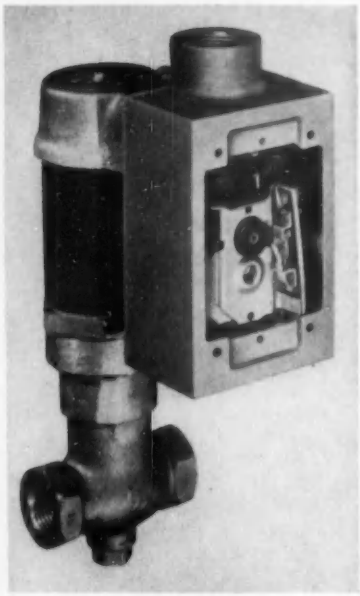
* Trade Name

Application engineering and conversion of tool machines and production processes to automatic control.

Magnetic Amplifiers • Inc
Tel. CYpress 2-6610 • 632 TINTON AVE., NEW YORK 55, N. Y.

NEW PRODUCTS

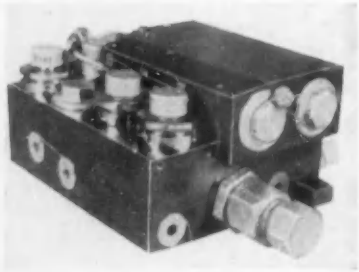
VALVES IN CONTROL



TIMER & SOLENOID VALVE:

New solenoid valves include a timer for operation according to either cyclic patterns or delays. By varying the on and off portions of the cycle, a proportional effect can be obtained. The valves operate on 115 vac 60 cps, and fit ⅜ in. and larger pipes. *Automatic Control Corp., 2390 Winewood, Ann Arbor, Mich.*

Circle No. 31 on reply card



SERVO SOLENOID VALVES:

The closed-center position of a new solenoid valve makes it particularly suitable for relay servos. The valves

Now available for general use . . .

The ¼ watt resistor so in demand it's been restricted to critical military applications

A fixed composition carbon resistor, the TYPE BTR combines superior electrical and mechanical characteristics in a size that permits important space and weight savings. More than 700,000,000 have already been used in proximity fuzes, guided missiles, and other critical military applications. Use BTR's, and you can be sure of the same quality—the same characteristics which enable the TYPE BTR to exceed MIL standards for this type of resistor. Send the coupon today for full data.

OUTSTANDING FEATURES

- **30% lower in weight and 25% smaller in diameter than IRC's famous TYPE BTS**
- **Wide range of resistance values—82 ohms to 22 megohms**
- **Excellent protection against humidity and temperature effects**
- **Good temperature, frequency, and load life characteristics**

Voltmeter Multipliers • Boron & Deposited Carbon Precistors • Insulated Composition Resistors • Power Resistors • Controls and Potentiometers • Low Wattage Wire Wounds • Germanium Diodes

Wherever the Circuit Says

Precision Wire Wounds • Ultra HF and Hi-Voltage Resistors • Selenium Rectifiers • Insulated Chokes • Hermetic Sealing Terminals

IRC®

INTERNATIONAL RESISTANCE CO.
Dept. 181, 401 N. Broad St., Philadelphia 8, Pa.
In Canada: International Resistance Co., Ltd., Toronto, Licensee

Send Technical Bulletin with complete data on TYPE BTR Resistor.

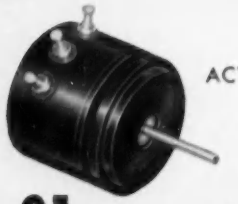
Name_____

Company_____

Address_____

City_____ State_____

NEW *Jewel-bearing "LO-TORK"*



ACTUAL SIZE

0.01 ounce-inches

PRECISION *wire-wound* POTENTIOMETER

Jewel bearings for lowest torque, and superior seal against surroundings that contain abrasive dust, make this new, Model LLT ⅞ Waters pot the ideal unit for high-reliability service where minimum torque is essential. With torque low enough to permit actuation by a Bourdon tube or a bimetallic thermal element, this potentiometer offers new advantages in sensitive-instrument applications as well as in computer, servo, and selsyn uses. Check your needs with these specifications:

Maximum torque: .....**0.01 ounce-inch**
Dissipation: .....**one watt at 80° Centigrade**
Resistances: .....**100 ohms to 100,000 ohms**
Weight: .....**½ ounce**
Outside diameter: 0.885 inch Body depth: ⅞ inch
Linearity: 0.5% standard; on special order, 0.25%
Winding angle: 354° standard; on special order, 360°
Ganging: to six decks with no increase in diameter.

Where the features of a ball-bearing potentiometer are desirable, specify Waters Model LT ⅞ "Lo-Tork" potentiometer.

Write for data sheets on jewel-bearing and ball-bearing precision wire-wound potentiometers.

Do you ever need pots that are "just a bit different"? Maybe we can help you — by modifying a standard Waters design or by taking a bold, new approach. Tell us your need and we'll tell you what we can do.

WATERS MANUFACTURING, inc.
Wayland, Massachusetts
Mail address: P.O. Box 368, So. Sudbury, Mass.
APPLICATION ENGINEERING OFFICES IN PRINCIPAL CITIES

MFG. INC.

NEW PRODUCTS

are basically four-way, especially modified for oil-hydraulic service at high temperature and pressure. Coils are for 28 vdc. They include pressure relief, thermal overload, electrically operated shut-off, and check valves. They go to 4,500 psi and **have constant gain characteristics.** This means that the flow remains constant regardless of load variations. They also tolerate return fluid temperatures of up to 400 deg F. *Vickers Inc., Detroit 32, Mich.*

Circle No. 32 on reply card

THREE-WAY VALVE:

A new line of three-way valves, solenoid-operated for 3,000-psi service, **handles 85 per cent higher flows** than conventional models, claims the maker. The Series 6000 valve will handle up to 6 gal per min through either ¼ or ⅜ in. tubing. In comparison, it is said, the average ⅜ in. valve passes only 3.2 gpm. The new item is essentially a ⅜ in. unit, but can be furnished with ¼-in. ports. Flow can be bidirectional. Solenoids are for 18 to 30 vdc. *Aircraft Products Co., 300 Church Road, Bridgeport, Pa.*

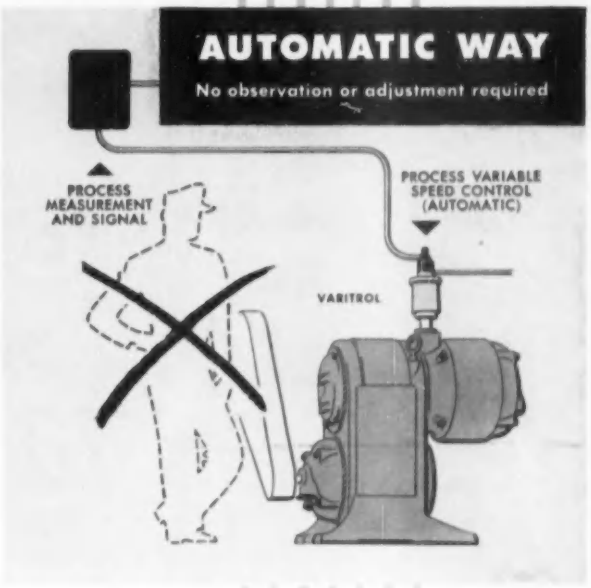
Circle No. 33 on reply card

RESTRICTED PORT VALVES:

By restricting the port of its Ratogate valves, Fischer & Porter makes available a wider variety of port openings. These new restricted ports can be adapted to all existing Ratogate valves now in service. *Fischer & Porter Co., 624 Jacksonville Road, Hatboro, Pa.*

Circle No. 34 on reply card

HOW VARITROL AUTOMATIC SPEED CONTROL saves Manpower



Human Error is Eliminated with

U. S. VARIDRIVE

MOTORS WITH VARITROL

Now, by controlling speed with Varitrol as a component of the U.S. Varidrive motor, speeds can be *automatically* changed in response to a signal *without* human attention. Varitrol pneumatic control regulates the speed of Varidrives in response to a signal from such variables as temperature, humidity, pressure, speed, liquid level, weight and tension. Varitrol automatic control of Varidrives offers an opportunity for improved quality of product, greater uniformity and more efficiency in plant flow handling. A profusely illustrated multi-color booklet explaining in detail the construction and operation of Varitrol automatic control is available. Write today for your copy.

U.S. Electrical MOTORS

U. S. ELECTRICAL MOTORS, INC. CEN-1
P. O. Box 2058, Los Angeles 54, Calif., or Milford, Conn.
☐ Send Varitrol Automation Booklet No. 1882
☐ Send U. S. Varidrive Booklet No. 1797
NAME_____
COMPANY_____
ADDRESS_____
CITY_____ ZONE____ STATE_____

MAIL COUPON NOW

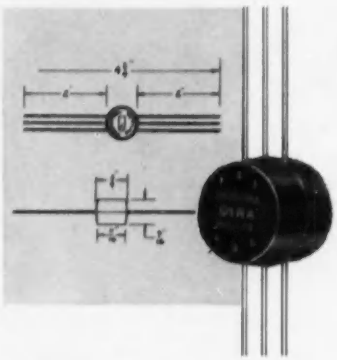
miniature

ENCAPSULATED

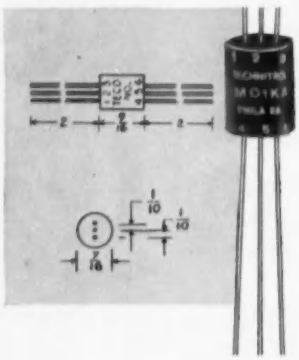
pulse transformers

custom-wound for your needs

Type MILX... for extreme environmental conditions



Type M... for subminiature and transistor circuits



Technitrol is equipped to design and produce pulse transformers to meet your particular requirements. Simply let us know your performance specifications. Technitrol's staff of engineers will test sample transformers under actual circuit conditions—assuring proper performance. All charges for this service are included in our low sample quantity price.

Technitrol also makes a full line of lumped and distributed parameter Delay Lines. You may choose from a variety of mountings, or again, our engineers will aid you in developing special designs.

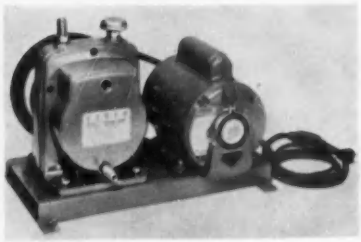
for additional information, write for Bulletin C166.

TECHNITROL
engineering company

2751 North Fourth Street • Philadelphia 33, Pennsylvania

NEW PRODUCTS

POWER SOURCES



0.1 MICRON VACUUM PUMP:

A new vacuum pump, little larger than an office typewriter, takes less than 5 min to reach its **0.5 micron pressure limit.** Working against no load, it delivers 20 liters per min. It's priced at $125.50. *Central Scientific Co., Chicago, Ill.*

Circle No. 35 on reply card

LEAKPROOF PUMP:

Hard-to-handle-liquids are safely moved by a new two-stage pump against heads of up to 230 ft. The new pump operates in temperatures up to 450 deg F with a 3-hp drive. It's made in a variety of materials ranging from cast iron to stainless steel. *Chempump Corp., 1300 E. Mermaid Lane, Philadelphia 18, Pa.*

Circle No. 36 on reply card

1600-CPS MOTORS:

A new series of 1600 cps motors, tachometers, and resolvers has been added to the maker's 400 cps line *American Electronics, Inc., 655 W. Washington Blvd., Los Angeles 15, Calif.*

Circle No. 37 on reply card

FILAMENT SUPPLIES:

Regulated to within 3 per cent or better, a new group of low-cost power supplies offers outputs from 6.3 to

Introducing...

The New BS&B Type 1460 Temperature Controller

Vapor-Tension Sensing System	
Bulb Range	Recommended Working Range
0-100° F.	20-90° F.
40-140° F.	60-130° F.
40-240° F.	90-220° F.
100-350° F.	175-335° F.

Gives Positive Fluid-Flow Control Through Diaphragm Operated Valves, Based On Temperature Variations

The new BS&B Type 1460 Temperature Controller or Pilot is equipped with an external vapor-tension thermal system to actuate the power unit in the pilot.

Except for this actuating mechanism and the temperature indicator which is an integral part of it, the 1460 Controller has all of the excellent features offered in the well-known BS&B Type 1440 Control Pilot—including the ¼" supply medium reducing regulator and two pressure gauges.

This unit is especially suited for translating temperature variations to direct flow-control of fuel, or of heating or cooling medium, through diaphragm operated valves.

FEATURES

- Vapor-Tension Sensing System
- Choice of Temperature Ranges
- Built-In Temperature Indicator
- Simple Adjustment Permits Either 100% Throttling Action—Or "On-Off" Snap Action Within A Wide Limiting Range.
- Parts Interchangeability With BS&B 1440 And 1450 Pilots Reduces Maintenance Cost And Parts Inventory.

Ask your BS&B Representative for more details—or write to . . .

BS&B

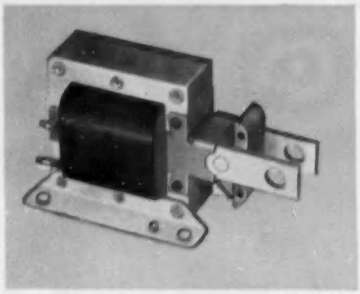
ANOTHER EXAMPLE OF PRODUCT LEADERSHIP

BLACK, SIVALLS & BRYSON, INC.

Controls Division, Dept. 4-ES4

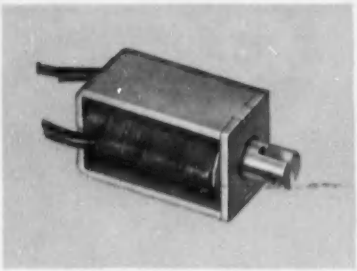
7500 East 12th Street Kansas City 26, Missouri

COMAR SOLENOIDS



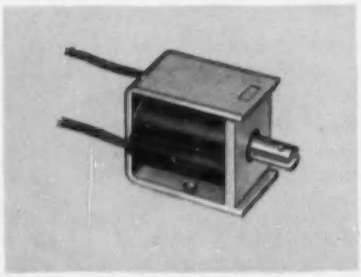
LAMINATED TYPES

AC only. Available in four types, for constant and intermittent duty. Voltages, 6 to 230 v. AC. Maximum stroke, 5/16" to 3/4", depending on type. Maximum pull, continuous duty, 2 to 8 lbs., depending on length of stroke. Maximum pull, intermittent duty, 3¾ to 20 lbs., depending on length of stroke. Supplied with lugs or leads.



SOLID FRAME TYPES

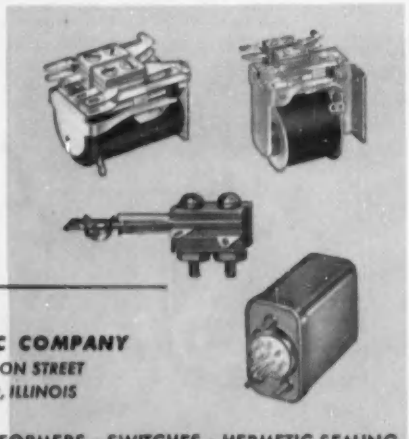
For AC or DC operation. Suitable for general industrial and commercial applications. Length of stroke up to 1". Range of pull: for AC continuous duty, 8 oz. to 12 oz.; for AC intermittent duty 2 to 3 lbs.; for DC continuous duty 1½ to 5 lbs., for DC intermittent duty 4 to 7 lbs.; depending on voltage and stroke.



MINIATURE TYPE

AC or DC operation. Compact size, 1" x 5/8" x 7/8". Ideal for use where space is limited. Length of stroke up to 5/32". Range of pull: for AC intermittent duty 10 to 20 ozs.; for DC continuous duty 1 to 4 ozs.; for DC intermittent duty 3 to 17 ozs.; depending on voltage and stroke.

If you use solenoids, relays or switches, it will pay you to contact Comar. Our complete engineering and manufacturing facilities will save you time and money. Send for details, no obligation.



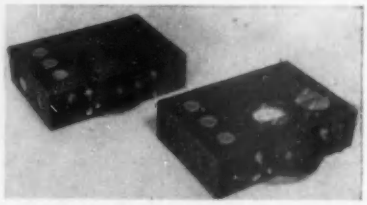
Comar
ELECTRIC COMPANY
3349 ADDISON STREET
CHICAGO 18, ILLINOIS

RELAYS • SOLENOIDS • COILS • TRANSFORMERS • SWITCHES • HERMETIC SEALING

NEW PRODUCTS

18.9 vdc. All of these items sell for under $35. *Kemlite Laboratories, 1813 N. Ashland Avenue, Chicago 22, Ill.*

Circle No. 38 on reply card



400-CPS POWER SUPPLY:

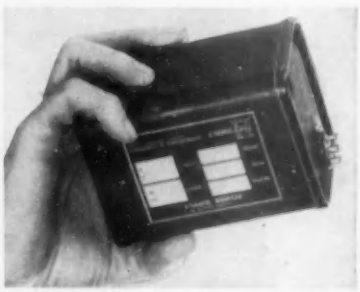
Small enough to fit in a brief case is a highly portable 400-cps power supply for testing air craft systems. It works from standard 115-volt 60-cps lines. **Its 10-va output is available at either 360, 400, or 440 cps.,** with vernier adjustment for interim frequencies. *Avien, Inc., 58-15 Norther Blvd., Woodside 77, N. Y.*

Circle No. 39 on reply card

HV POWER SUPPLIES

An offering of **16,000 vdc** from a 1.5 vdc **input** is the feature of a 6-oz power supply for cathode ray and infrared applications. It's rugged enough to stand 20,000 g's or more, and temperatures to 100 deg C. *Universal Atomics Corp., 19 E. 48th St., New York 17, N. Y.*

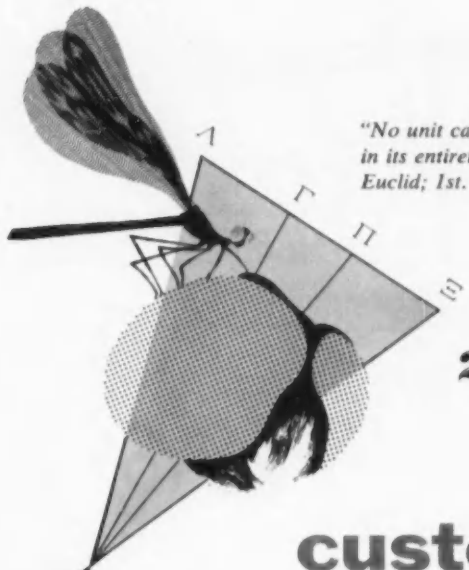
Circle No. 40 on reply card



VOLTAGE STANDARD:

A really wide range of inputs—from 70 to 135 volts at 360 to 440 cps—result in 5 vdc at 1 amp output within 0.2 per cent. A 0.1 amp drain enables a 35-to-135-volt input swing. It is offered as a replacement for conventional battery packs and bridge-type null circuits and strain gage elements. The hermetically sealed plug-in case is about 3 by 3½ by 4½ in. *Timely Instruments & Controls Corp., 1645 W. 135 St., Gardena, Calif.*

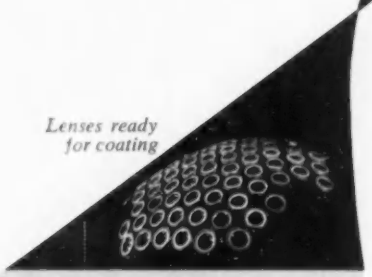
Circle No. 41 on reply card



"No unit can be seen simultaneously in its entirety."
Euclid; 1st. theorem of optics.

2076 eyes

custom optics in quantity



Lenses ready for coating

It doubtless took ages to develop the Dragonfly's many faceted eye. Today, at Kollsman, highly complex optical systems such as photoelectric trackers, periscopic sextants, telescopes for radar bombing systems, and others, are not only designed expeditiously, but are produced in quantity.

Kollsman represents something new in optics. This is because the Kollsman Optical Department, established in 1940, grew up within a company devoted for over 28 years to designing and producing some of the most complex instruments and controls in the aviation industry. Aviation moves as fast as tomorrow's guided missile. It is this quality of up-to-dateness you will find in our entire optical operation.

Here we have the finest talents and tools to be found anywhere for the solution of your optical problems. Consult us without obligation on any or all phases of

DESIGNING • DEVELOPING • TESTING • PRODUCING MODERN OPTICS

COMPLETE DEVICES AND SYSTEMS

- Critical wide angle photographic lenses (11 elements)
- Binoculars
  - Large 7x50 for marine use
  - Small 6x20 for sportsmen
  - Large 6x42 wide angle for aircraft and marine use
- Drift Sights
- Sextants
  - Periscopic • Hand held • Photoelectric
- Periscopes used on anti-aircraft Skysweepers
- Telescopes used in radar bombing and navigation systems
- Astrocompasses • Photoelectric Trackers
- Sky Compasses

COMPONENTS

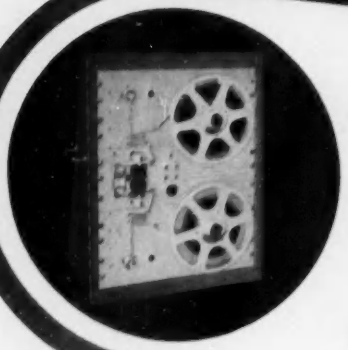
- Lenses, windows and mirrors, diameters ¼ inch to 3 feet, flatness 1/10 wavelength parallelism fractions of a second
- Aspherical objectives and mirrors
- Collimating objectives
- Cones and rods for ranging devices
- Hyper- and hypo-hemispherical sighting domes
- Prisms: Roof, Retro, Porro, Dove, Amici, Leman, Abbe, penta, rhomb, etc., of high resolution and minimal pyramidal and angular errors
- Annular prismatic scales • Special reticles

WRITE for brochure "2076 Eyes"

kollsman INSTRUMENT CORPORATION

80-08 45th AVE., ELMHURST, NEW YORK • GLENDALE, CALIFORNIA

SUBSIDIARY OF *Standard* COIL PRODUCTS CO. INC.

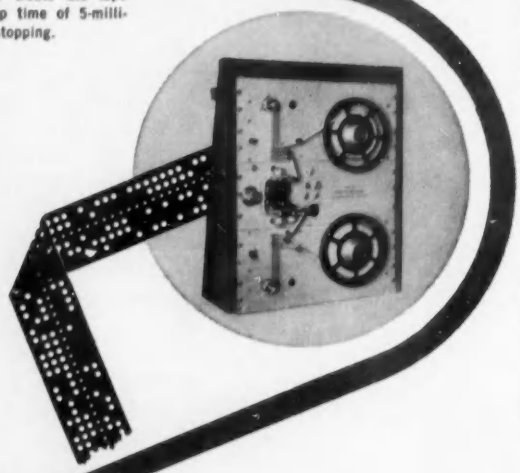


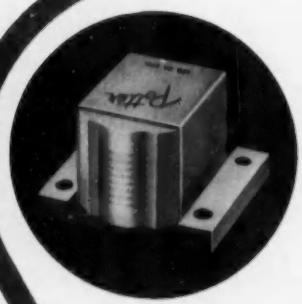
headquarters for digital magnetic and perforated tape handlers

Model 902 Magnetic Tape Handler treats the tape gently while providing a start/stop time of 5-milliseconds. Fully reversible without stopping.

Model 903 Perforated Tape Reader provides a 5 millisecond start time and stops on the character at 300 characters per second and on the character following a stop code at 600 characters per second.

The Potter Digital Magnetic Head eliminates "digit drop-outs" due to oxide collection. Phosphor bronze head mount provides close tolerances insuring complete interchangeability of tape from one machine to another.





Whether your data processing requirements call for perforated or magnetic tape handling, Potter offers a complete line of high-speed equipment to meet your needs . . . for either intermittent or continuous playback with speeds of up to 60 inches per second and start/stop times of less than 5-milliseconds!

Servo-controlled tape drives permit fast starts and stops without tearing or spilling tapes. At 30 inches/second speed, less than ⅛" of tape is consumed in a start/stop cycle!

For complete specifications on Perforated Tape Readers, Magnetic Tape Handlers and Digital Magnetic Recording and Playback Heads, write TODAY:

POTTER INSTRUMENT CO., INC.
115 Cutter Mill Road
Great Neck, New York

NEW PRODUCTS

PORTABLE POWER SUPPLY:

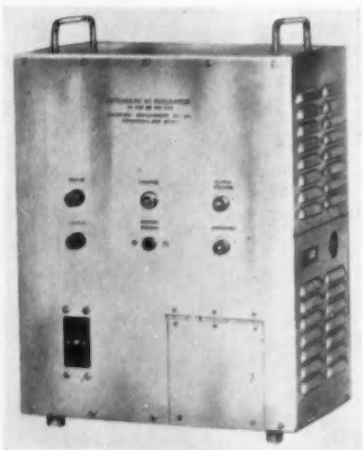
A 0-to-500-vdc output at 200 ma is the offering of a portable, typewriter-sized power supply. It's priced under $300 and contains a host of quality features. *Lambda Electronics Corp., 11-11 131 St., College Pt., 56, N. Y.*

Circle No. 42 on reply card

16 NEW SUPPLIES:

A group of new power supplies hits just about all the standard voltage ranges currently in vogue. They're regulated to within 3 millivolts, and tackle up to 1.5 amps. *Kepco Laboratories, 131-38 Sanford Ave., Flushing 55, N. Y.*

Circle No. 43 on reply card



TWO-INPUT REGULATOR:

A new regulator accepts either 115 or 230 volts by a single switch selection, controlling the output within 1 per cent, and delivering 6 kva. It's said to include a fail-safe arrangement to guard against overvoltage conditions. *Electronic Measurements Co., Lewis St., Eatontown, N. J.*

Circle No. 44 on reply card

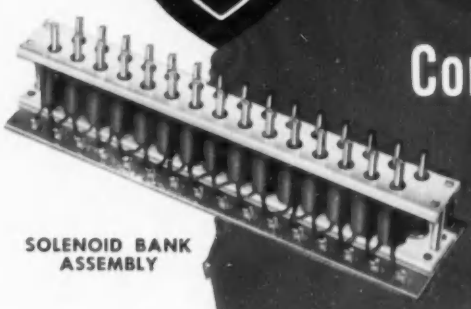
Specify GUARDIAN®

FOR

Complete Control Assemblies

HOUSED – HARNESSED – CABLED

ready to plug in!



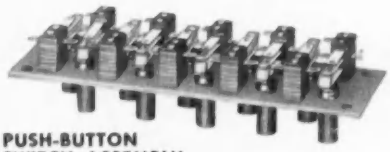
SOLENOID BANK ASSEMBLY

CONTROL BOX TESTER

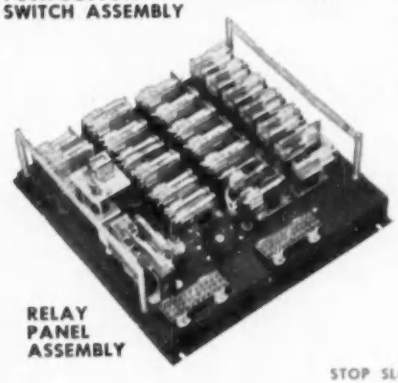
SPECIAL "COMPUTIT" ASSEMBLY

STOP these fellows in their tracks!

STOP HIGH PRICES



PUSH-BUTTON SWITCH ASSEMBLY

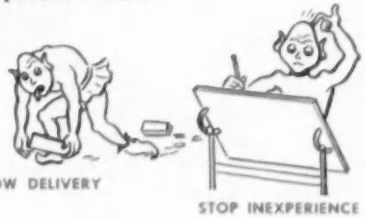


RELAY PANEL ASSEMBLY

Units shown here typify the wide range of Complete Control Assemblies *designed, engineered* and *produced* by GUARDIAN. With absolutely dependable controls such as these, GUARDIAN engineers have solved seemingly insurmountable problems for both the military and commercial industry.

Let GUARDIAN'S 25 years of engineering experience help you save money, conserve space and prevent costly rejects. Whether you require relay banks, solenoid banks, control box testers, "Computit" assemblies, push-button switch systems—or an entirely different "package" control —Guardian has complete facilities to design and produce them.

STOP POOR QUALITY



STOP SLOW DELIVERY

STOP INEXPERIENCE

STOP POOR DESIGN

STOP REJECTS

GUARDIAN—for the ultimate in open, enclosed, sealed and hermetically sealed controls

GUARDIAN ELECTRIC

1623-D W. WALNUT STREET CHICAGO 12, ILLINOIS

A COMPLETE LINE OF CONTROLS SERVING AMERICAN INDUSTRY

to the DIEHL

SERVO MOTOR FAMILY

The Diehl Servo Motor Family is expanding. Rapidly, too—because it's twins this time!

They're not identical twins, to be sure—one's a **SIZE 11**, the other **SIZE 15**, 400 cycle a-c induction servo motor—but both are built to exacting specifications, and both have all the fine family traits that mark all the Diehl Servo Motors ranging in power output up to 1 HP. ***Fast response . . . more power output . . . long life***—yes, they have all the dependable qualities you look for in the servo motors you specify for automatic control systems.

The **SIZE 11**, as either a six or four pole motor, has a locked torque (hot) of 0.63 ounce-inches minimum. The **SIZE 15** motor, with either eight or four pole winding, has a locked torque (hot) of 1.45 ounce-inches minimum. Check the other specifications below—you'll see how perfectly these new Diehl 400-cycle motors fit into your automatic control picture ***today.***

SPECIFICATIONS

Diehl Number	B15M1-1	B11M1-1	Remarks
Government Designation	Mark 7 Mod 0	Mark 14 Mod 2	
Frame Size	15	11	
Number of Phases	2	2	
Reference Phase Volts	115	115	
Control Phase Volts	57½	57½	Parallel connection
	115	115	Series connection
Frequency (c.p.s.)	400	400	
Current Input at Stall	0.110	0.053	Amps. per phase
Power Input at Stall	6.1	3.5	Watts per phase
Impedance at Stall	1030	2175	Ohms per phase
Torque at Stall	1.45	0.63	Oz.-in. minimum
No Load Speed	4800	6200	RPM minimum
Number of Poles	8	6	
Duty at Stall	Continuous	Continuous	
Moment of Inertia	3.3	1.07	Gm/cm² average
Weight	7.3	4.5	Ounces average

other available components

CE4-56

A.C. SERVOMOTORS • A.C. SERVOMOTORS WITH A.C. TACHOMETERS • A.C. SERVOMOTORS WITH D.C. TACHOMETERS • A.C. AND D.C. TACHOMETERS • D.C. SERVO SETS • RESOLVERS

Diehl

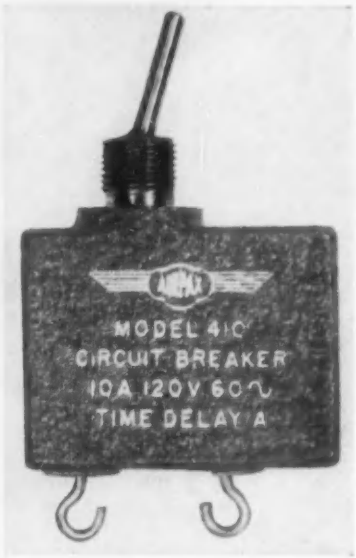
DIEHL MANUFACTURING COMPANY

Electrical Division of THE SINGER MANUFACTURING CO.

Finderne Plant SOMERVILLE, N.J.

NEW PRODUCTS

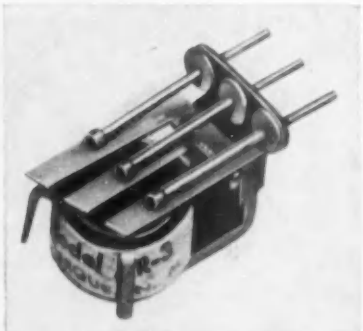
RELAYS AND SWITCHES



CIRCUIT BREAKER:

Miniaturization has expanded its domain. The tiny circuit breaker shown here **handles up to 10 amps** at frequencies from 60 to 1,000 cps. It occupies little more than a cubic inch and withstands all sorts of rough treatment. As seen, the switch shank gives it a role as a main power control. *Airpax Products Co., Middle River, Baltimore 20, Md.*

Circle No. 45 on reply card

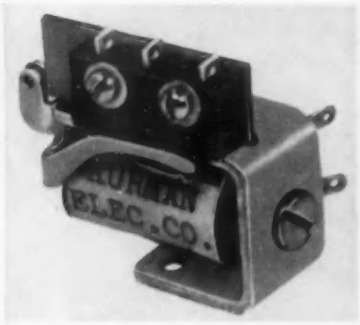


REED RELAY:

Either two or three reed models of a frequency sensitive relay are now available **for the detection of frequencies**

between 100 to 500 cps. Coil impedances run from 5 to 10 k ohms. It weighs 0.4 oz and is offered for remote monitoring or control systems using radio or wire links. The reeds are driven by 2.5 volts with a 7.k-ohm coil. *CG Electronics Corp., 305 Dallas St., N. E., Albuquerque, N. M.*

Circle No. 46 on reply card



HEAVY-CURRENT RELAY:

A new miniature telephone-type relay operates in 10 ms, **breaking up to 5 amps at 125 vac.** Less than 100 milliwats operates the snap-action contacts. Coil resistance is 6,000 ohms. It can be had with hermetic sealing. *Kurman Electric Co., Inc., 35-18 37th St., L. I. C., N. Y.*

Circle No. 47 on reply card

DELAY RELAYS:

A new series of **thermal time delay relays** in dust-tight shells is available with either normally open or closed contacts and heaters rated up to 230 volts. Ten delays range from 2 to 180 sec. *G-V Controls Inc., 28 Hollywood Plaza, East Orange, N. J.*

Circle No. 48 on reply card

CONTROL COMPONENTS

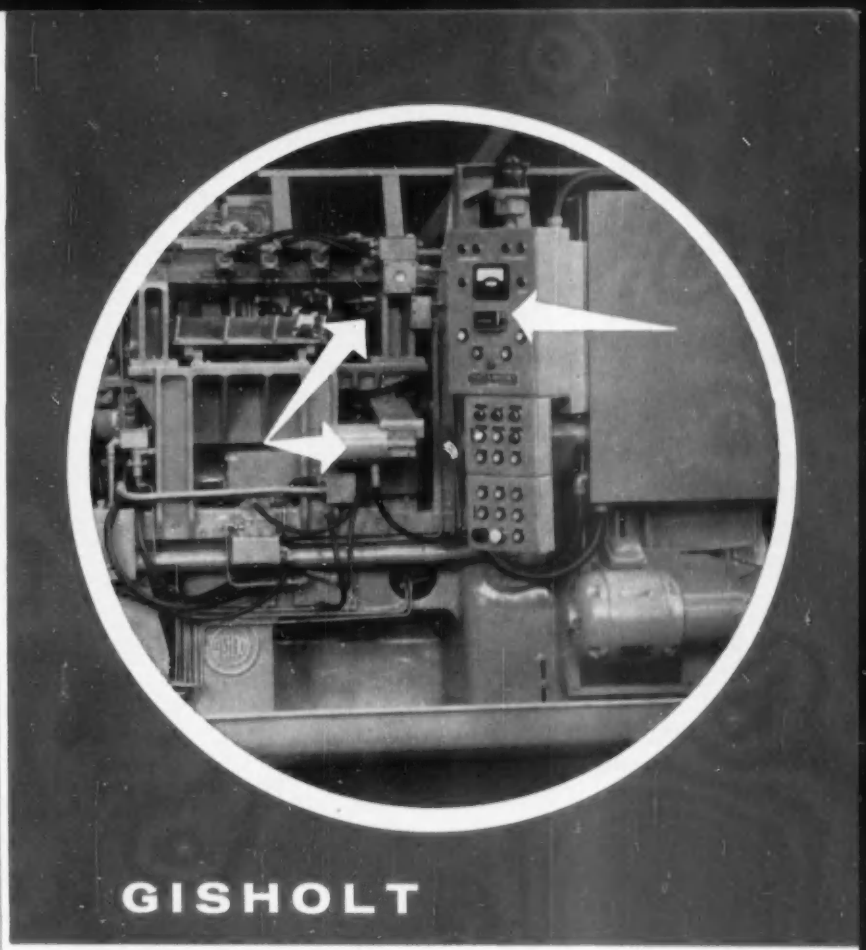
POTTING KIT:

Intended for use by electronics engineers interested in exploring the feasibility of potting circuits, a kit now available has elements setting at room temperature, flexible molding material, dip insulating plastic, and heat-cured material. *Plastronics, P. O. Box 96, Winter Hill 45, Mass.*

Circle No. 49 on reply card

PHOTOELECTRIC PICKUP:

By actuating a time delay as well as a normal relay, a modified photoelec-



always "ON TARGET"...
automatically with

AUTOMATION GAGING

Quantity, quality or both . . . whatever your primary objective may be, Pratt & Whitney Automation Gaging — in-process checking plus "feed-back" control for automatic machine adjustment — can help you hit your production targets. Here are: *Greater Accuracy* than ever before possible, *Increased Output*, because there are no production shut-downs to gage parts and re-adjust the machine; and *New Economies* through fewer rejects.

Is Automation Gaging practical and proved? This Gisholt Automatic with P & W Gaging produces a finished precision rotor for fractional horsepower motors *every 10 seconds.* Machine operation with self-correction, size control, inspection of finished parts and sorting are all completely automatic.

Don't wait and wonder about automation. GET THE FACTS. Write to P & W *today* outlining your machining-gaging problems and let Pratt & Whitney Specialists show you how to hit your production target . . . automatically!

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8 Charter Oak Boulevard, West Hartford 1, Connecticut
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MACHINE TOOLS GAGES CUTTING TOOLS

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Meet the Industrial Field Engineering Staff of North Electric Company. Their job is to serve your design groups as engineering consultants (without fee) in determining whether and how to use relays as control components.

This exclusive North engineering service pays off for you, and for North, because of the many cases in which they can aid in the development of simplified dependable systems . . . with all relay controls. These competent engineers are based near the key centers of industry. One of them can be at your doorstep promptly if you will write, wire or call the Galion office — Galion 2-4201 . . . regarding

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as components or control assemblies

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NORTH ELECTRIC COMPANY

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NEW PRODUCTS

tric pickup stops conveyor belts when pile-ups occur, but retains its normal counting function. *Autotron Co., Box 722-AC, Danville, Ill.*

Circle No. 50 on reply card

SEALED SWITCH:

Snap-action contacts are sealed under a rubber cover as part of a low-cost design. It's 1⅛ in. in diam and ⅝ in. high. Operating differential is 0.010, **life a million cycles,** and rating up to 15 amps. *Electra Mfg. Co., 4051 Broadway, Kansas City, Mo.*

Circle No. 51 on reply card

SILICON DIODES:

Intended **for high frequency applications,** a new glass-cased silicon diode offers a shunt capacitance of only 0.8 mmfd. The Type S6G is urged for 30 to 60 megacycle circuits. *Transitron Electronic Corp., Melrose 76, Mass.*

Circle No. 52 on reply card

COIL FORM:

A threaded ferrite core enables accurate inductance values with Ferrocube part No. 2781016E1, which, when wound with 250 turns of No. 28 wire, **yields 300 to 800 microhenries** at 400 kc. *Ferroxcube Corp. of America, 97 Marshall St., North Adams, Mass.*

Circle No. 53 on reply card

SLIDE RULES:

The maker of a new metal slide rule says that its yellow-green color is seen more easily than the conventional white. The rules are calibrated to seven decimal places, made in 6- and 10-in. models, and sold in fine leather cases. *Pickett & Eckel, Inc., 5 S. Wabash Ave., Chicago, Ill.*

Circle No. 54 on reply card

LOW-COST CYLINDERS:

Prices range from $15 to $36 for a new line of 1¼-to-3¼-in. bore cylinders. They handle either **250-psi air or 500-psi water.** A nylon bearing eliminates any metal to metal wear. They are available from stock with a variety of mounts. *Alkon Products Corp., 206 Central Ave., Hawthorne, N. J.*

Circle No. 55 on reply card

Notable Achievements at JPL

***FIRST TO FLY FM-FM TELEMETERING...** From JPL's 3-band FM-FM telemetering System flown in 1944, to its present extremely versatile, compact, transistorized 18-band system, telemetering has been an important factor in the successful development of JPL guided missiles.*

Significant firsts in this field are:
In 1948, a 10-band FM-FM System with 15 measurements.
In 1953, an 18-band FM-FM System with 36 measurements.
In 1954, a 14-band FM-FM System with all audio circuits transistorized.

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The success of the Corporal and other JPL guided missile programs is dependent on constantly improved instrumentation techniques. Development, a major portion of the Telemetering Group activity, is directed toward improving system flexibility, accuracy and reliability. This activity is tailored to both immediate and long range instrumentation requirements of the many Laboratory missile programs.

The use of transistors and modern magnetic elements, together with progressive packaging techniques developed from intensive JPL studies, result in greatly improved reliability in missile-borne and ground-recording equipment. In addition, advanced communication studies are being utilized in the design of advanced telemetering equipment to the constant improvement of this art. An example of applied theory, is the use of tracking filter techniques in the communication link—resulting in a significant improvement in telemetering data accuracy.

The size and character of the "Lab" fosters a personal contact and close relationship between data-user and telemetering engineer. This close telemetering support is a basic reason for the development of better ways of measuring drag for the aerodynamicist, motor pressures for the propulsion expert, stresses for the missile designer and of monitoring complex electronic circuits which are the responsibility of the guidance specialist. This close cooperation has become a prime factor in the growth of the laboratory into one of the most successful guided missile development centers in the world.

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GREIBACH MICROAMMETER MODEL 500

Battering Blows

. . . can't impair its accuracy

THE PROBLEM: Test readings from outlying control points are **vital** to a leading processing company. Servicemen make **frequent** field trips, by truck, to obtain necessary information. But, even short rides over rough, unpaved roads caused conventional meters to lose accuracy and become damaged . . . often making it **impossible** to collect reliable information. Maintenance costs were staggering . . . the meters spent **more time** in repair than in service.

THE SOLUTION: Greibach engineers answered this and hundreds of similar problems by developing an extra tough **line** of meters with a **unique Bifilar Suspension** so rugged it withstands 500 g's shock **without damage or loss of accuracy** . . . never needs recalibration in **normal** use. Greibach meters are electrically rugged too! Accidental overloads to 100,000% can't harm them . . . full scale sensitivities to one microampere and accuracy better than 0.25% are easily attained . . . 0.1% increments are readable **without** tapping. The light beam pointer can be **viewed from any angle accurately** . . . parallax problems are ended! Greibach meters are manufactured in a wide range of sizes and types — for current, voltage, resistance measurements in standard, thermocouple, edgewise panel and differential units. Their extremely dependable operation is perfect for systems' work.

Full Greibach meter performance is given in Bulletin #602. Send for your copy today!

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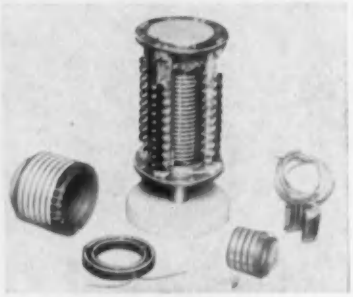
PIONEERS IN MATERIALS RESEARCH, ELECTRONIC COMPONENTS, PRECISION INSTRUMENTS AND SYSTEMS ENGINEERING

NEW PRODUCTS

INDICATOR LIGHTS:

Two small indicator lights, one $\frac{1}{2}$, the other $\frac{13}{32}$ in. in diam, are now offered for crowded panels. *Hetherington, Inc., Sharon Hill, Pa.*

Circle No. 56 on reply card



SLIP-RING ASSEMBLIES:

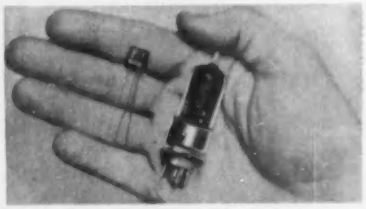
A new line of slip-ring assemblies features noise levels in the microvolt range. Their **sizes range from 0.060 to 12 in. OD** and they carry up to 12 circuits in either pancake or drum styles with matching brush assemblies. The rings are molded in epoxy resin, nylon, Kel-F, and Plaskon glass-reinforced resin. *Airflyte Electronics Co., 535 Ave. A, Bayonne, N. J.*

Circle No. 57 on reply card

SUPER-LIFE CELL:

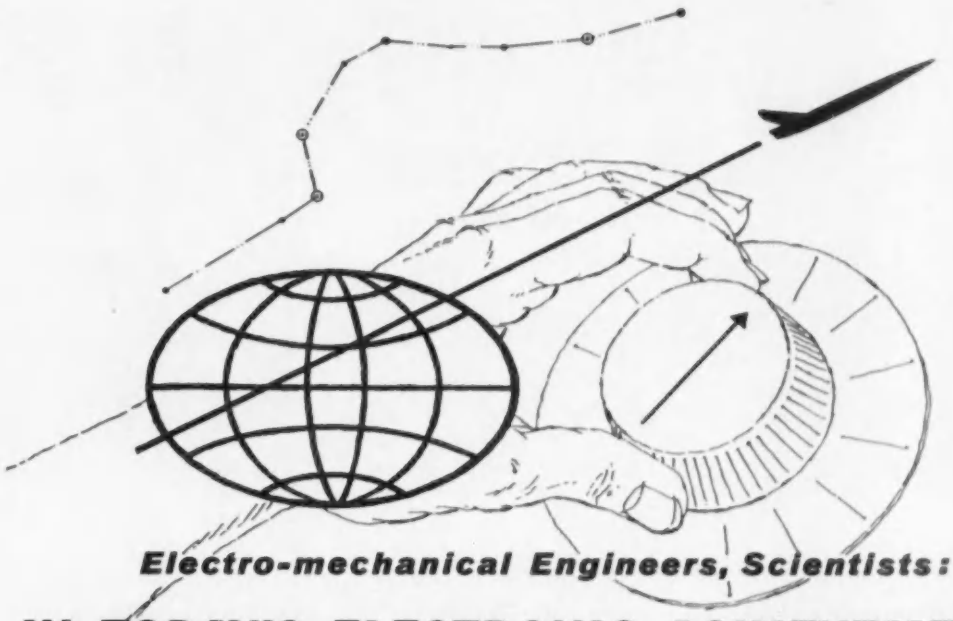
A new battery is said to combine the weight and size advantages of a silver-zinc cell with the long-life characteristics of a nickel-cadmium couple. The new cell can deliver 6 **amp hr in a 5-oz, 5-cu-in. case** at 1.25 volts. *Yardney Electric Corp., 44 Leonard St., N. Y. 13, N. Y.*

Circle No. 58 on reply card



SILICON TRANSISTORS:

Germanium Products Corp. **claims to be first with these volume-produced silicon transistors.** Two lines are offered, one handling emitter rating of 2 volts, the other 5. The transistor shown in the photo above is said to have characteristics comparable to the tube. Eight models are cur-



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NEW PRODUCTS

rently available. The new transistors are to be marketed by *Bogue Electric Mfg. Co., 52 Iowa Ave., Paterson 3, N. J.*

Circle No. **59** on reply card

SNAP-ON RECTIFIER:

A pair of new selenium rectifiers with special snap-in terminals is designed **for use in printed circuits.** They have ratings of 30 and 65 ma at 110 vac. *Radio Receptor Co., Inc., 251 W. 19th St., N. Y. 11, N. Y.*

Circle No. **60** on reply card

MOUNTINGS:

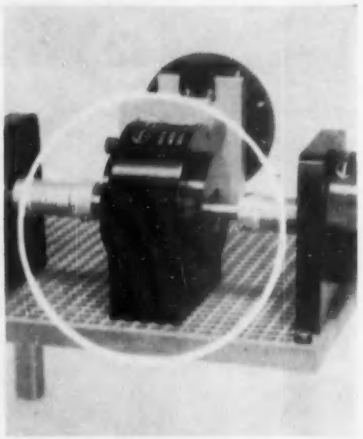
A new group of mounting brackets for terminal or resistor boards is said to withstand shocks up to 2,000-ft-lbs. Sizes range from 1⅛ through 3⅞. *Raytheon Mfg. Co., Waltham 54, Mass.*

Circle No. **61** on reply card

POWER DIODES:

Axial lead silicon rectifiers are now in production to **handle up to 600 volts peak inverse** and forward currents averaging ½ amp at 100 deg C. The ¼-cu-in items can be printed-circuit mounted. *Transitron Electronic Corp., Melrose 76, Mass.*

Circle No. **62** on reply card

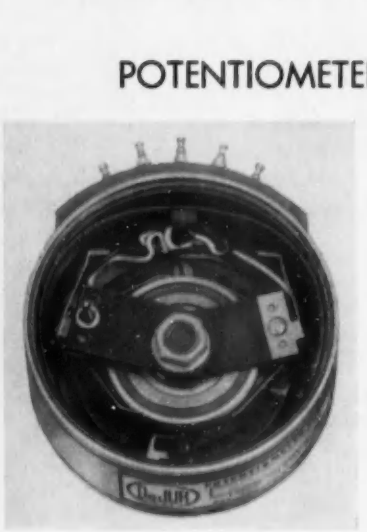


UNIVERSAL GEAR TRAIN:

Neatly encased in a stout wooden box are change gears for arranging 20 ratios from 20:1 to 1600:1 in the breadboard case shown above. The gears are stainless steel and their housing aluminum. Bearings are either Oilite or ball bearings. *Bowmar Instrument Corp., 2425 Pennsylvania St., Fort Wayne, Ind.*

Circle No. **63** on reply card

POTENTIOMETERS IN CONTROL



ADJUSTABLE BRUSHES:

Here's a pot with two independently adjustable brushes. The device is 2 in. high and dissipates 4 watts. A variety of functions is available. *Electronic Sales Div. of DeJUR-Amsco Corp., 45-01 Northern Blvd., Long Island City 1, N. Y.*

Circle No. **64** on reply card

LINEAL TRAVEL POT:

Either single or dual pots in a ½-in.-diam case are now available for travels up to 6 in. Resistances up to 60,000 ohms per in. with single-turn taps are offered with resolution down to 0.0008 in. They meet mil specs. *General Components Co., 801 Eighth St., SE, Minneapolis 14, Minn.*

Circle No. **65** on reply card

HIGH-TEMP POT:

Designed to perform in temperatures up to 150 deg C and under severe vibration conditions, a new ⅞-in.-diam pot offers ¼-per-cent linearity and resistance to 45,000 ohms. *The Gamewell Co., Newton Upper Falls 64, Mass.*

Circle No. **66** on reply card

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Ohmite Amrecon relays have proven their exceptional ruggedness and long life in years of service. Now, four popular stock models—DOS, DOSY, DO, and CRU, in 65 different types—are available from stock.

Models DO and DOS fill many industrial needs for a compact, lightweight relay that handles power loads usually requiring much larger, heavier units. They are particularly adaptable to aircraft and mobile equipment where severe shock and vibration are encountered. The increased operating sensitivity of Model DOSY relay, equipped with twin coils, makes the DOSY adaptable to a wide range of electronic control circuits, such as plate circuit controls. At 115 VAC or 32 VDC, noninductive load, Models DOS and DOSY have contact ratings of 15 amp; Model DO, 10 amp; and Model CRU, 5 amp. Available in a wide range of coil operating voltages and contact combinations.

Current ratings up to 25 amp, AC or DC. Also made-to-order models in many contact combinations and coil voltages.

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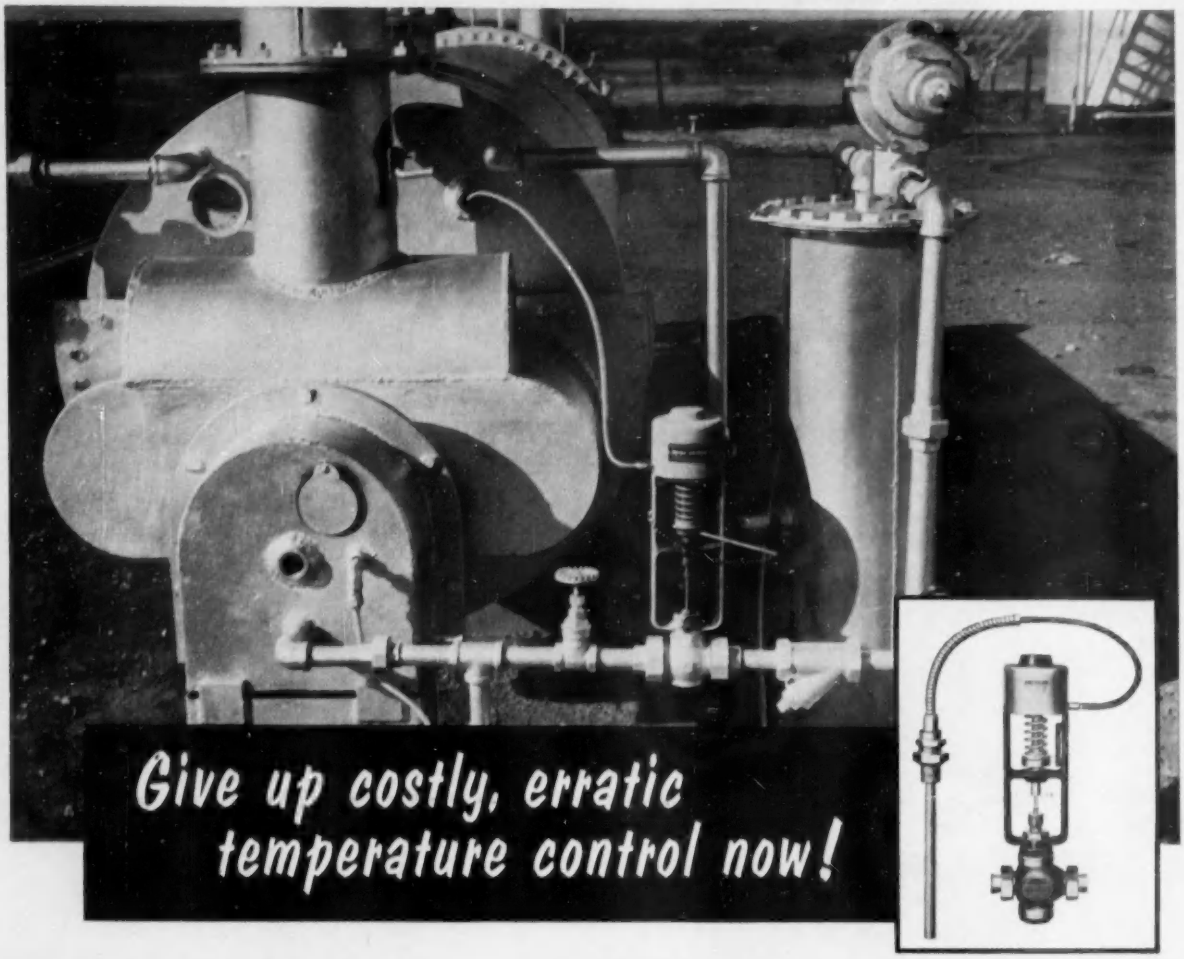

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(100) MOTOR SPRING. Neg'ator Div. of Hunter Spring Co. Bulletin 310Mb, 25 pp. Here's a handsome takeoff on the theory that overexpanding one end of a coil spring results in a simple mechanical motor with output torque on the expanded end. Drawings get A-plus.

(101) SPECTROGRAPHIC SUPPLIES. Jarrell-Ash Co. Catalog SS-8-55, 24 pp. Contains descriptions and prices of spectroscopic chemicals available from England, rods, electrodes, and powders, and plates and film from the U. S., and literature from both nations.

(102) AUTOMATIC CONTROLS. The Mercoid Corp. Catalog 856, 52 pp. Mercoid puts details on nearly 120 classes of automatic equipment between heavy embossed covers. For an idea of the catalog's scope: pressure controls, 12 pp.; temperature controls, 12 pp.; relays, 4 pp.; thermostats, 4 pp.

(103) CONVERSION THEORY. Epsco, Inc. Paper, 8 pp. Epsco's Technical Vice-president Bernard M. Gordon discusses theory of analog-to-digital conversion and the operation of two converters developed by the Andor Controls Div.

(104) INSTRUMENTING A PLANT. Fischer & Porter Co. Bulletin 90-242-11, 12 pp. This discussion of measuring and controlling process variables in a sewage treatment plant gets fancy dressing in the shape of highly interesting diagrams that show how two plants are instrumented.

(105) CERAMIC TRANSDUCERS. Gulton Mfg. Corp. Brochure, 12 pp. Covers applications, physical and electrical properties, resonant frequency characteristics, and standard sizes and shapes.

(106) MONITORING SYSTEMS. The Autocall Co. Bulletin, 34 pp. Describes five kinds of variable-actuated annunciators and presents easy-on-the-eyes schematic diagrams of each one. Covers such characteristics as operating voltages, windows, types of control cabinets.

(107) TECHNICAL WRITING. Technical Marketing Associates, Inc. Pamphlet (5½ x 8 in.), 10 pp. A. D. Ehrenfried, director of TMA, authored this booklet, which takes the working engineer on a light-hearted trip through the most salient points to be considered in writing a technical paper.

(108) SOLENOID VALVES. Barksdale Valves. Catalog 5-C, 8 pp. Describes 3-way and 4-way "Crescent" valves for air and for air, water, and light oil. Ranges are 0-150, 30-150, and 50-500 psi. Gives characteristics, flow patterns, and overall dimensions.

(109) VARIABLE-SPEED DRIVES. Magnetic Amplifiers, Inc. Bulletin S 580-5-55, 8 pp. Describes two sizes of controllers, one rated up to ½ hp and the other to 1½ hp. Absence of tubes, capacitors, etc., makes the units "nonelectronic". Speeds range from 2,000 to 40 rpm for a ratio of 50:1.

(110) APPLYING GATING PACKAGES. Computer Control Co., Inc. Paper, 20 pp. Here's a lucid treatment of the elements that make a computer "logical". The discussion centers around the 3C-PAC gating package.

(111) AIR AND VACUUM PUMPS. Leiman Bros., Catalog 755, 12 pp. This full coverage of the Leiman line includes data on construction, dimensions, capacities, and performance curves.

(112) CHEMICAL PUMP. O.K. Machine & Tool, Inc. Gives features of a 300-gph pump whose Teflon construction allows it to handle all chemicals except molten alkali metals and fluorine at up to 300 deg F and at high pressures.

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(113) CYLINDERS, VALVES, ETC. The A. K. Allen Co. Master Catalog, 40 pp. Describes valve-in-head, single- and double-end cylinders; pilot, solenoid, and hand air valves; a spring-return clamp; and dial feed tables. Table chart relates cpm to number of positions, plate diameter, weight added.

(114) STATHAM LITERATURE. Statham Laboratories, Inc. Assorted bulletins, 12 pp. Cover transducers, pressure transducers, and accelerometers.

(115) ELECTROMETER. Applied Physics Corp. Bulletin, 4 pp. Discusses a more flexible version of the Cary Model 30 Vibrating Reed Electrometer. It's called Model 31. Ranges are 1-1,000 millivolts and 3-30 volts.

(116) SWITCHES, ETC. General Control Co. Bulletin 4b/Ge, 4 pp. Covers pushbutton, lever, limit, and foot switches, synchronous-motor and electric timers, and control panels.

(117) WATER-TIGHT CONNECTIONS. The Pyle-National Co. Bulletin 629, 6-pg. gatefold. Gives data on knurled and ribbed grips and elbows for portable cords and cables used in all types of electrical equipment. Charts in detail male and female types, conduit sizes, and sizes of cords and cables.

(118) PRESSURE GAGE. Callery Chemical Co. Bulletin PG-2, 4 pp. Variations in a core-sensitive, bellows-actuated transformer are recorded on a meter. That's the principle and here's one of the features: the bellows can be switched for various applications. Range: to 1,000 deg F.

(119) PRESSURE REGULATOR. Black, Sivalls & Bryson, Inc. Bulletin 11-55-107, one sheet. At maximum reduced pressure of 40 psi, this unit's set pressure varies less than 0.1 psi. Filter handles anything larger than 40 microns. A 100-psi regulator spring is available.

(120) HIGH-PRESSURE METERS. Granberg Corp. Bulletin 571, 8 pp. Discusses two rotary positive displacement units (1,600 gpm max at 300 psi and 200 gpm max at 1,000 psi) and a Duo-Rotor for up to 28,000 gpm at 1,000 psi.

(121) LUBRICATION PUMPS. Tuthill Pump Co. Catalog 108, one sheet. Shows dimensions, parts, and performance curves for four compact, cartridge-type designs.

(122) CONNECTORS. Barco Mfg. Co. Catalog 407, 4 pp. Big, clear drawings illustrate split-flange connectors for air, steam, and gases, and their components. Tubing sizes range up to ¾ in. They're not supposed to loosen despite twists and turns.

(123) NMC REPORTS. Nuclear Measurements Corp. Bulletin, one sheet. NMC tested its proportional counters against five others on the basis of counting range, background, efficiency, decontamination, cost, time, etc. Here are results.

(124) LEVEL CONTROLS. Machinery Electrification, Inc. Assorted bulletins, one sheet each. Deal with probes for dairy, food processing, and general applications, and with two types of liquid level controls.

(125) PROCESS CONTROL. Brown Instrument Div. of Minneapolis-Honeywell Regulator Co. Bulletin 7202, 12 pp. Covers three Tele-O-Set instruments for control of process variables: a recorder and indicator (essentially one and the same) and a controller, which balances two pressures to achieve setpoint.

(126) TELEMETERING. Stavid Engineering, Inc. Brochure, 7 pp. Here's some lowdown on the Beacon unit developed for the Army Signal Corps. The transmitting-receiving-calibration system is discussed in terms of range of repetition, samples per second, and rate of change. Accuracy is 2 per cent of range.

(127) RADIO BEACON UNITS. Stavid Engineering, Inc. Brochure, 5 pp. Covers two of Stavid's developments for the Air Force. One operates on the S band frequency, the other on the X band. Both ac-dc units have interchangeable receivers.

(128) CAPACITORS. The Gudeman Co. Bulletin 271-2, 4 pp. About two paper-dielectric Feed-Thru units designed for minus 55 to plus 85 deg C and for minus 55 to plus 125 deg C. They can handle twice their rate of voltage for two minutes and have a life of 250 hrs under 140 per cent rated dc voltage.

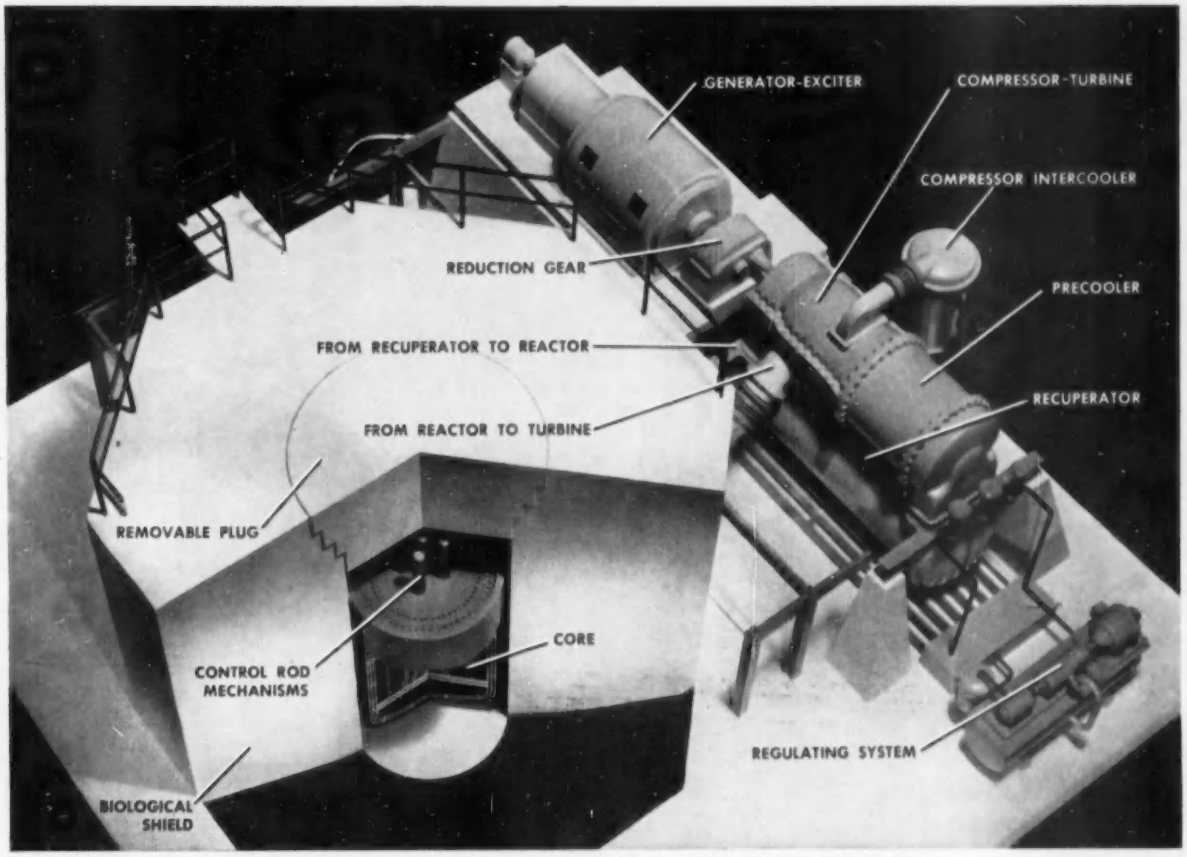
(129) QUICK-CONNECT VALVE. Naresco Equipment Corp. of National Research Corp. Bulletin, 1 sheet. Explains principle behind a vacuum valve which, though not strictly a control component, eliminates enough vacuum-pumping or gas-filling systems for a notation.

(130) HELICAL GEAR DRIVES. Link-Belt Co. Book 2651, 16 pp. High points here are charts that tie applications to load classes, give hp and torque ratings for double- and triple-reduction drives, and offer selection tips. Loving care went into the illustrations.

(131) ROTARY SWITCHES. Allis-Chalmers Mfg. Co. Bulletin 14 B 8112, 8 pp. These control and instrument devices are engineered for looks, too. Adding stages and replacing contacts are made easy, and positive contact and definite contact positioning are assured. Spread tells what's available.

(132) ADHESIVES. Adhesives & Coating Div. of Minnesota Mining & Mfg. Co. Catalog, 12 pp. The engineer might say this one gets off to a slow start. But halfway through appear massive charts on applications and properties of adhesives, coatings, and sealers. An admirable job.

(133) MORE ADHESIVES. Rubber & Asbestos Corp. Data chart, 2 pp. Another "borderline case" that's too fact-filled to pass up. This one is about R&A's products exclusively, but that shouldn't matter if the information is adequate. And it is.



Model of a closed-cycle gas-cooled reactor power plant designed by Ford Instrument in conjunction with American Turbine Company.

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For more information on this new type of reactor write Ford Instrument Company.

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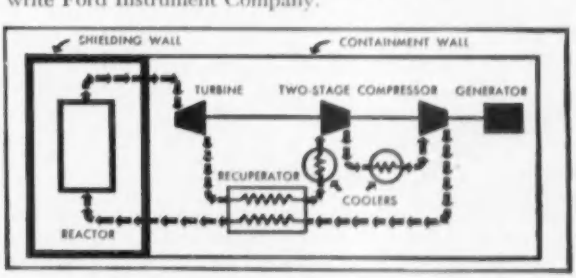

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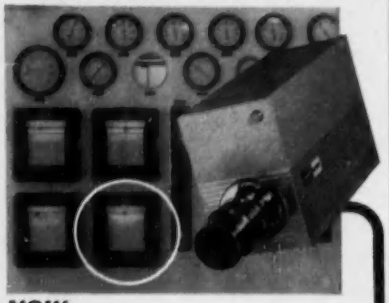

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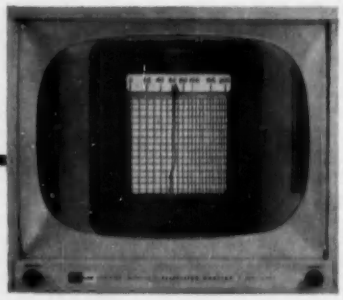

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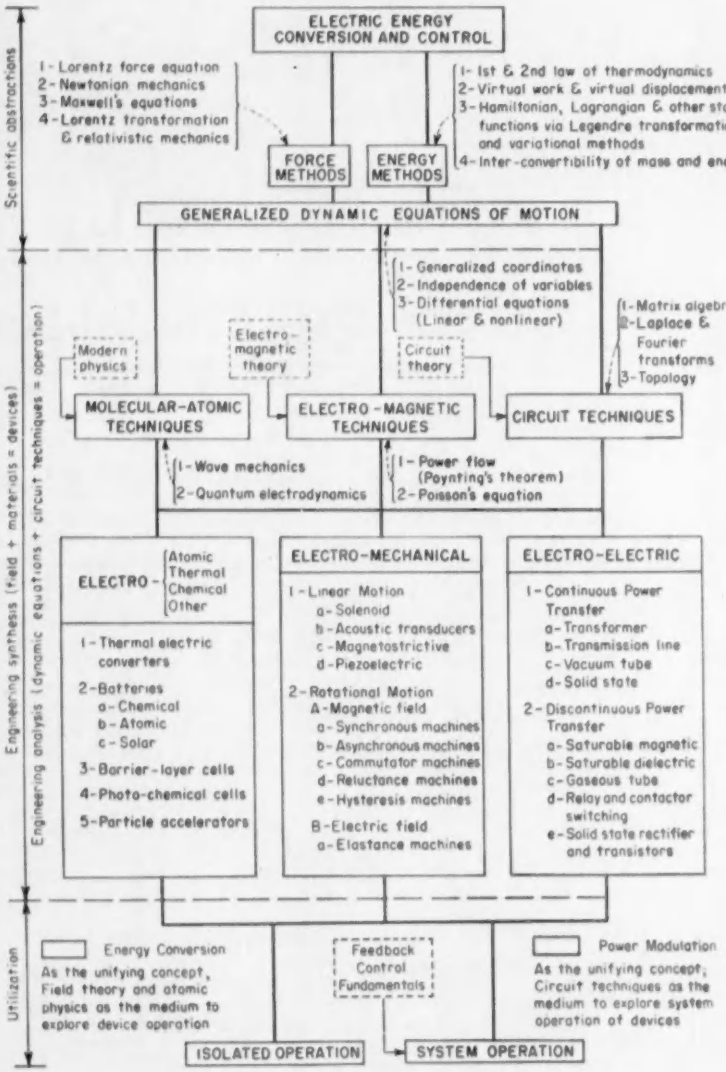
For a Better Crop

From "A New Educational Program in Energy Conversion" by Gordon S. Brown, A. Kusko, and D. C. White, Dept. of Electrical Engineering, Massachusetts Institute of Technology. Paper presented at Winter General Meeting of AIEE, Jan. 30-Feb. 3, 1956, and published in "Electrical Engineering", February 1956, pp. 180-185.

When MIT scrapped its conventional courses and laboratory work in machinery, it was lending a reputable voice to the growing conviction that this type of curriculum was fast becoming an anachronism. And in framing a substitute program, Tech was making it very plain that its criticism was not meant to be negative, but constructive. Though still in an embryonic stage, the new schedule has reached the point where students can participate in it and educators can vocalize about it. The authors do the latter in this paper.

The decision to change the old-line methods of teaching engineering was prompted by an awareness of the engineer's growing responsibilities. MIT thinks he stands a better chance of realizing these responsibilities if they are inobtrusively introduced to him

FIG. 1



while he is a student. This is the prime purpose of the new program, which will soon rest on the shoulders of the present junior staff. The hope is that ultimately it will take on the scope envisioned in Figure 1, which charts the "interrelations of science engineering in energy conversion and its utilization".

Eight "core" subjects, organized under the general titles of "Energy Conversion" and "Information Processing", make up the electrical portion of the revised program. The authors emphasize that the subjects under energy conversion "are not mere substitutes or equivalents for the traditional subjects on ac and dc machinery or power transmission. On the contrary, their content recognizes that the imaginative processing of energy is one of the major responsibilities of engineers. The impact of new materials, new environments, new energy sources, new calculating machines, as elements of our new abundance, has increased the breadth, versatility, and depth of scientific competence demanded of tomorrow's engineer."

The curriculum to further this "scientific competance" gets into full swing in its third year with the start of two of the three subjects under energy conversion: "Fields, Materials, and Components" and "Electrical Energy Converters". The student will be sent into these courses with a strong background in mathematics and electricity and magnetism, and by the time he enters his fourth year he'll be well prepared for the third subject, "Electric Power Modulators". Thus, his program "starts with field theory and relates it to the microscopic concept of materials, continues through the combination of these materials to perform energy-processing functions, treats the basic principles of energy-processing devices, and culminates in the study of energy-conversion systems composed of interconnected devices". The paper deals with energy conversion exclusively, the idea evidently being that the information processing portion of the curriculum speaks for itself; and of the three subjects discussed, the last two get the most attention.

"Fields, Materials, and Components" introduces the student to key principles, gives him advanced generalizations about fields, and starts him on vectors. In the laboratory he'll map fields and study dielectric and magnetic properties of materials under changing conditions. When he advances to "Electrical Energy Converters" he'll see how interactions of fields with materials may lead to methods for controlling and convert-

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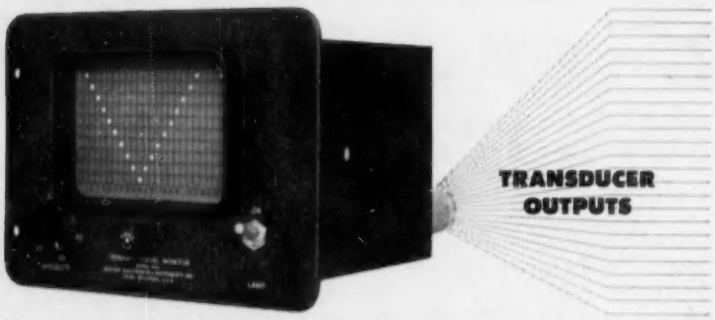

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ABSTRACTS

ing energy and how he may realize devices for doing these things; and he'll learn why a careful analysis of what is meant by the coordinates of a system is important. In the lab he'll study energy storage in reactors, transformers, and magnetic amplifiers; force-displacement relationships in electromechanical devices; and analog circuits and frequency-responsive behavior of transducers. When he gets to "Power Modulators", he'll study the performance of systems in which they are found, and will determine their parameters and transfer functions. The stress here will be on the control or dynamics of energy-processing devices.

The authors submit four examples from the text material to illustrate the approach used. The examples are the scaffolding for note material, home problems, and laboratory experiments. One of the four submitted seems to be more inclusive than the others, principally because its protagonist, a generalized two-phase rotating machine, generates much of the theory of continuous electromechanical energy conversion in the "Power Modulator" section. An idealized version of the rotating machine (Figure 2) is used in determining field

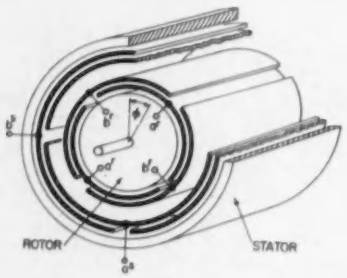

FIG. 2

equations for the air-gap volume in terms of the current densities in the winding sheets and other conditions of rotor velocity and excitation frequency. Specific problems are solved by impressing required constraints on the electrical or mechanical terminal quantities in the form of interconnections, applied voltages, and torques. Transformations are used to obtain sets of differential equations with non-time-varying coefficients under special conditions; these equations are either directly solvable, lead to equivalent circuits, or require solution by computer. Thus, the example sets the stage for consideration of the complete class of rotating-machine problems and solutions.

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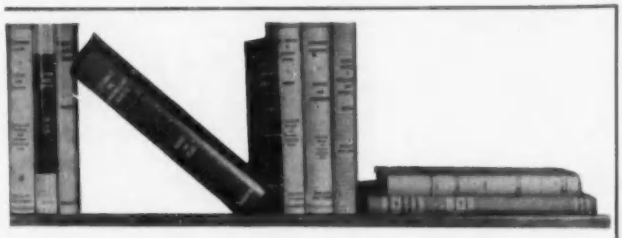

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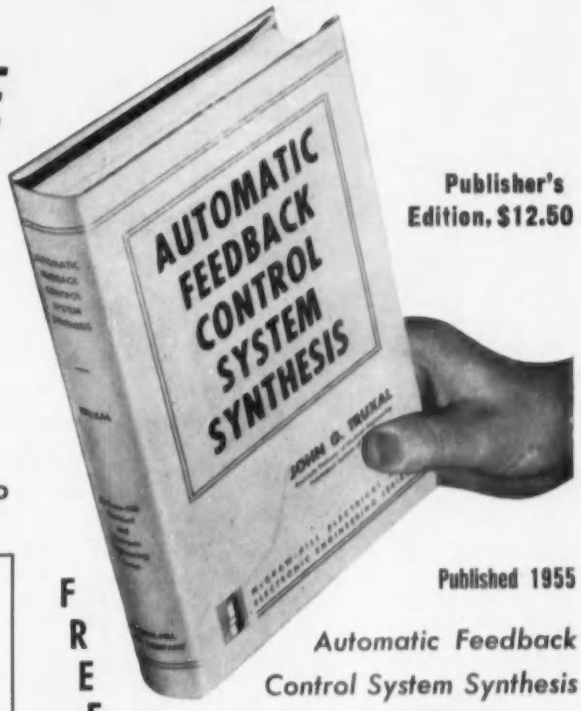

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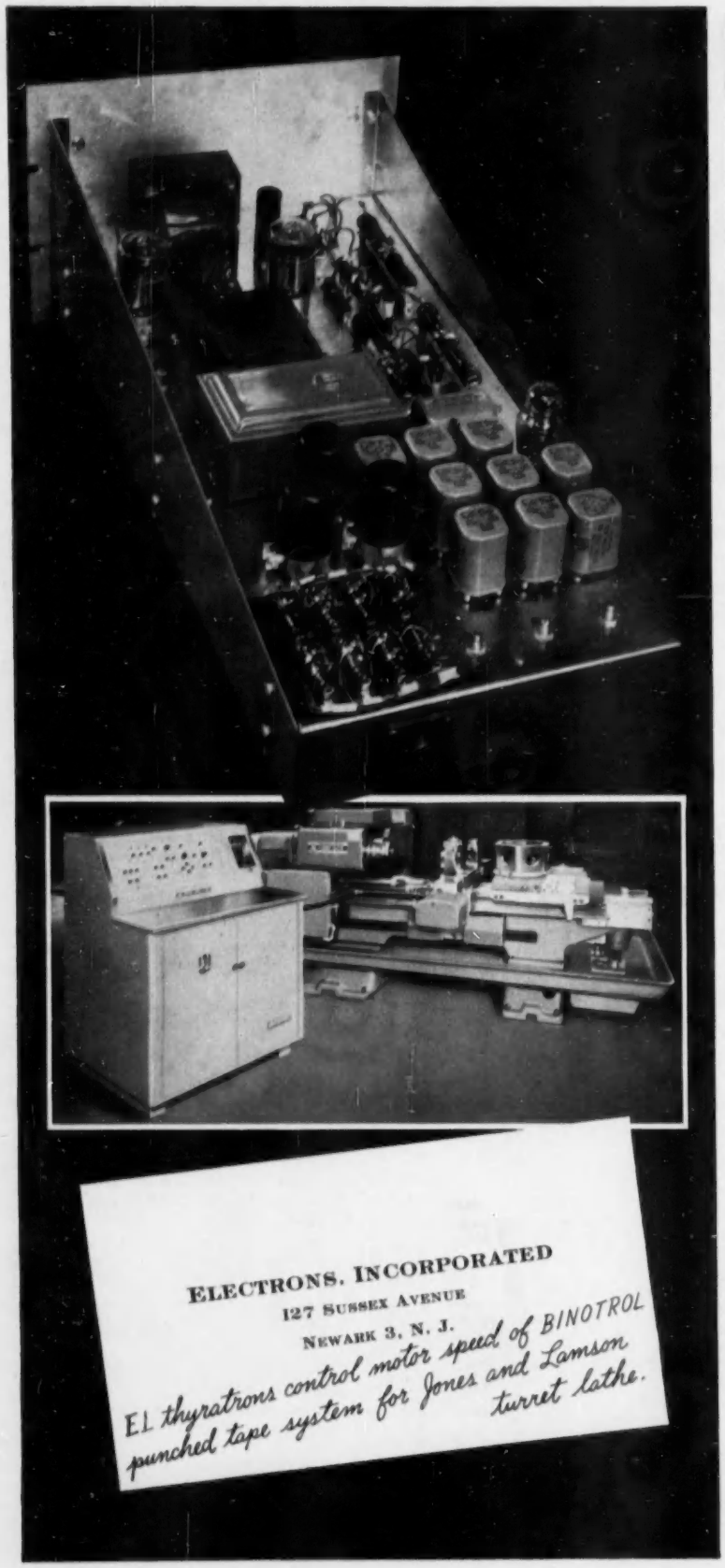

ABSTRACTS

fore the new curriculum can be called firmly established. It's especially anxious to broaden the scope of study to include other forms of energy conversion in which the electrical form is used, such as conversion from heat and light.

Robot Warehouses

From "Automatic Warehousing" by Gifford Kittredge, Lamson Corp., "Proceedings of the RETMA Symposium on Automation," September 1955.

Roughly 30 per cent of manufacturing costs today are directly attributable to materials handling. There is a possibility of adding a number of indirect costs to this area to increase the percentage.

The author likens the flow of materials to that of fluids, and states that the analog has much validity in the design of materials handling systems. One of the principal characteristics of the average modern warehouse is automatic palletization for fork lift trucks.

The author describes the Lever Brothers warehouse at Hammond, Ind., as an example of a modern automatic materials handling installation. Eighteen production lines are shunted onto two trunk conveyors which cover the 800 ft between the production area to the center of the warehouse. One of these conveyors handles spray products, the other hard soaps. The cartons of spray products can be immediately sent to a truck loading platform or to six storage lines that feed automatic pallet loaders.

Automatic sorting is done by photocells that scan each carton for markings located when the cartons are printed. After pallet loading, the pallets are immediately handled by fork lift trucks or placed on elevators for transmission to lower floors.

The second main conveyor's hard soap cartons are hand-palletized because of the variety of packages used.

Another advanced warehousing operation is carried out at the Heinz plant in Pittsburgh. Here, the output of 14 production lines is stored long enough to make a slug or train, which is then fed to one of four main conveyors to the storage area. Here a dispatcher supervises the automatic pallet loading of the trains, and dispatches them to different floors of the warehouse.

Like the Lever Brothers, the Schmidt Brewing Co. in Philadel-

phia uses a combination of direct-output-to-loading-area lines with lines to automatic pallet loading for warehouse storage. With this system a dispatcher can determine the exact load destined for a given truck and send the rest of the plant's output to storage.

Among the future possibilities for this field are automatic depalletization for the removal of materials from warehouses to loading vehicles; increased use of closed-circuit television to coordinate operations in large installations; radio controlled or punched card controlled fork lift trucks; and means for identifying cartons for inventory control systems.

Control by Refraction

From "The Differential Refractometer for Automatic Control of Fractionating Columns", by O. D. Larrison, F. W. Purl, and H. R. Harris, Phillips Petroleum Corp. ASME-IRD paper 55-IRD-11, presented at ISA Conference, Los Angeles, September 1955.

The authors make a good case for using differential refractometers in continuous process control applications. Although the article emphasizes fractionating hydrocarbon mixtures, the step-by-step approach to the construction and application of this end-point analyzer guides the way to use for other continuous processes.

A refractometer measures the refractive index of a liquid. If strong correlation exists between the refractive index and optimum product, the refractive index controls product quality through a closed loop. In this article the authors cover the theoretical basis of the instrument's development, its construction, its application to fractionators, some specific applications, and methods and choice of control.

Several column conditions or functions (and hence product) can be correlated with the refractive index of a carefully selected sample point in the column. But in most cases that have been studied the refractive index gradient of the fractionator correlates best with the composition gradient of the heavy (key) component of the separation. The control point is usually the tray at which the plot of the tray height vs. refractive index shows the greatest slope.

In a particular fractionating process (demethylcyclopentanizer), analysis of many product samples against refractive index shows that the percentage of the key component can be measured by the refractive index. Thus it follows that if the refractometer automatically varies heat input to the col-

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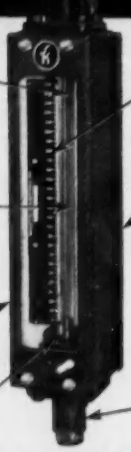

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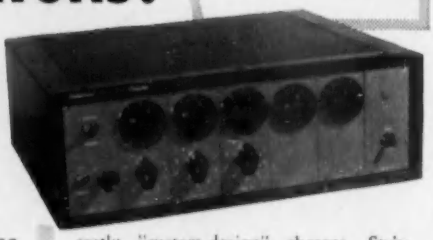

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ABSTRACTS

umn so that the refractive index of the sample tray remains nearly constant, the significant overhead product will remain very nearly constant, too.

The differential refractometer can control the process in several ways. The ultimate object of the closed loop is to control the heat input to the fractionator so that the refractometer measurement compares with the desired index.

Two methods of control and prominent considerations in their choice are: ▶overhead product method—used when less than 90 per cent of the feed is going into the overhead product; when the concentration of a key component in the overhead product is controlled; and when the previous control system employs rate-of-flow control of the overhead product (this saves expense of additional instrumentation). ▶kettle product method—used when less than 90 per cent of the feed is kettle product; when the concentration of a key component in the kettle product is controlled; and when the previous control system employs rate-of-flow control of the kettle product.

The paper also includes an exploded view of the basic refractometer and a detailed explanation of its operation. Other illustrations show overhead product and kettle product method control arrangements for a fractionator, and charts (24 hours) for a particular process with and without refractometer control. As would be expected, the controlled refractive index (7 per cent) shows up favorably compared with the uncontrolled index (over 65 per cent variation). In terms of overhead product this means an improvement in quality of eleven to one using the controlled system.

The authors conclude their paper with succinct comments on operator education in the use of the refractometer, and a discussion of preventive and unscheduled maintenance.

Automating Odd Gears

From "Automation of Non-Circular Gear Cutting by Univac 120" by Alan H. Stillman, Remington Rand, and F. W. Cunningham, Cunningham Industries, Inc., "Proceedings of the RETMA Symposium on Automation," September 1955.

Noncircular gears are rarely used except for the generation of logarithmic functions. Their possibilities for generating other functions are generally dismissed in favor of cams be-

cause of the complex calculations required to make the gears.

A Fellows gear shaper was converted to tape control by Cunningham Industries as part of an effort to simplify the fabrication of special noncircular gears. The conversion utilizes punched tape to operate a stepping motor, which in turn operates a synchro-transmitter-directed servo. The steps of the stepping motor are the equivalent of 0.15 deg of cutter rotation, 1 deg of gear blank rotation, or 0.00025 in. out from the center. However, the time required for calculating a particular set of gear dimensions and preparing a tape is about 100 hours.

A Univac 120 was used to reduce this time to about four hours, including the time to cut the gears, but not including the time required to set up the program. What this is, the authors do not state, but the explanation of the steps suggests that more than a few hours is required to familiarize a programmer with the task. All told, four separate programs are required before the punched tape converter has something that the gear cutter can work with. These four programs must be repeated for each of a pair of special gears, of course.

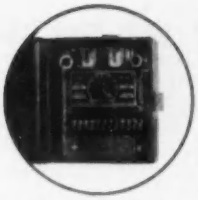
The setup is probably one of the first examples of extensive computation directly associated with a machine tool control. As there are few metal-cutting operations that require more exact design calculation than odd-shaped gears, this may well be the apex of calculation-control apparatus. However, the authors should take account of the economics of the situation: the rental time for the computer, the programming costs, the cost of the time on the cutter, etc., to establish the status of this procedure in contrast with the drafting-room and job-shop labor and time otherwise required. Even if this system fell behind on a single-piece basis, it might gain a clear lead when it's considered that the tape can be stored.

End-Point Analysis

From "Process Control by End-Point Analysis and Associated Data Reduction Systems", by Sibyl M. Rock, ElectroData Corp., and Jack Walker, Consolidated Electrodynamics Corp. ASME paper presented at ISA Conference, Los Angeles, September 1955.

This paper reviews end-point analysis and data reduction techniques in the process industries and considers what advanced techniques may be needed in the future.

Initially the authors discuss end-



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point analyzers in terms of two classes: physical instruments that measure and control physical properties of matter, and chemical instruments, whose output is a function of chemical separation or molecular structure. A table shows the present and immediate future use of these instruments (for gases, liquids, and solids) in the plant for monitoring and control, and in the laboratory.

Another section discusses the role of control accessories for end-point analyzers. These include analog accessories (recorder-monitors, programmers, computer-controllers, and scanners) and digital accessories (loggers, transmitters, and digital computers).

The second part of the paper treats the use of digital computers in batch analysis of complex streams, discussing these computers in optimum product programming as a precursor to future closed-loop control. A series of six plant operation block diagrams chronologically extrapolates process analysis techniques. The first diagram (1955) starts with the method of manually carried batch samples, through a general purpose computer to human decision and manual control set. The last diagram (19??) deals with the blue-sky closed-loop arrangement of continuous sampling, automatic end-point analysis through the computer to formulate decisions, and automatic resetting of controls.

On formulation of decisions the authors make some interesting comments. The computer "is not yet programmed to assume the routine decisions of either the control engineer or the management. The chief reason is that the pattern for these decisions is not yet generally *formulated*. This word 'formulated' is the key as to why a great many things have not been done by computers. Before the computer can be programmed to do any operation, that operation must be thoroughly understood and expressed as a logical, fully defined sequence of computations and decisions. Automatic control loops are closed only where the variable having the greatest effect is known, where the point at which the control is highly effective has been determined, and where the relation between the two is established. In such simple cases the computation required is seldom more than a comparison with a standard, which can be done by a small device.

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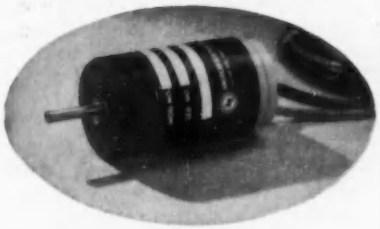

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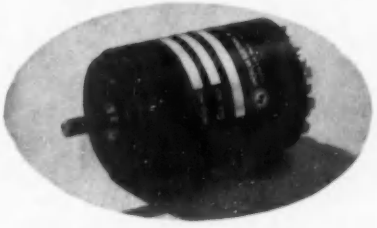

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loops and subsequent formulation of their operation in terms of specific measurement and central factors. With this expanded know-how, larger programs will be drawn to incorporate some of the work now being done by the engineers and members of management. As formulation evolves, larger and larger portions of the operation can be controlled by fewer adjustments. When the large batch problems are routinely solved and are thoroughly proved, systems may incorporate several small loops with their own special-purpose computers. Selected output from these may be fed in sequence into a large computer. This computer will then combine the partial data, and on the basis of the computed results, drive some of the controllers themselves. Until the gaps in present knowledge are filled in, and the formulation advanced, this is not feasible."

Briefly Noted

AN ELECTRONICALLY CONTROLLED MACHINE TOOL. "*Electronic Engineering*" (*England*) January 1956, p. 37. Electric & Musical Industries, Ltd. the British partner in an agreement on an international exchange of control information, showed what it can do on its own when it tackled a copy milling machine used by a Norwich, England manufacturer. Before EMI went to work on it, the machine, installed at Laurence, Scott & Electromotors, Ltd., turned out cams by following a master pattern. When EMI was done, there was no need for the master.

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THE DESIGN OF THE IBM TYPE 702 SYSTEM. *C. J. Bashe, P. W. Jack-*

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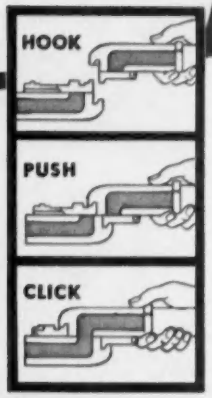

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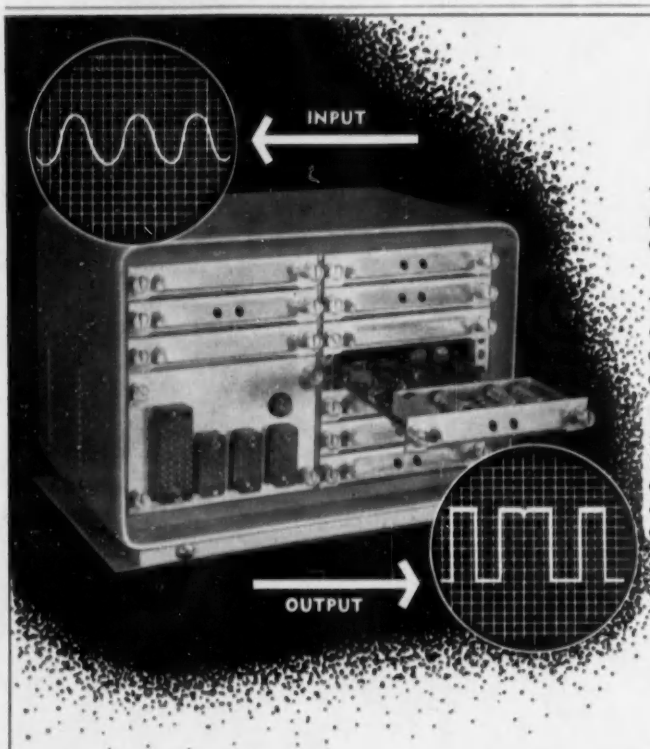
son, H. A. Mussell, and W. D. Winger, International Business Machine Corp. Communications and Electronics (AIEE), January 1956. An extensive discussion of the functions and features of this computer intended primarily for automatic processing of business records.

A Digital Potentiometer. S. K. Dean and D. F. Newell. Electronic Engineering (England), February 1956. Describes an instrument for measuring voltage in discrete integers in either binary or decimal scale. Basically, the instrument compares an input voltage with a series of references voltages. Any difference energizes circuits that add or back-off necessary voltages until balance is reached.

Practical Tips on Keeping a Technical File. James J. Lahm, Westinghouse Electric Corp. Machine Design, Feb. 9, 1956. Discusses organization and maintenance of a personal technical file as a valuable working tool for the engineer.

Precision Switches. "Instrumentation", Minneapolis-Honeywell, January-February, 1956, p. 20. Discusses units for process, motion, level, and bulk flow control, and for conveyors and counting and weighing.



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A. WYSCHNEGRADSKI: ZUR THEORIE DER AUTOMATISCHEN REGELUNG. *J. L. Geronimus. 60 pp. Published by VEB Verlag Technik, Berlin NW 7, Germany.*

A. M. LJAPUNOW: STABILITATSPROBLEME DER BEWEGUNG. *J. L. Geronimus. 88 pp. Published by VEB Verlag Technik, Berlin NW 7, Germany.*

In his interesting book, *Sketches of the Work of Eminent Russian Personalities in Mechanics*, (Moscow, State Publishing House, 1952, 519 pp.) J. L. Geronimus epitomizes the professional careers and summarizes the most important contributions of leading 19th Century Russian workers in pure and applied mechanics. These men worked on certain technical and scientific problems that are yet of interest.

Among these problems is that of determining the dynamic stability of linear and nonlinear systems. Such determination comprises a central problem in the analysis and synthesis of present-day automatic control systems. Because of this importance, and of the long-continued influence of two men—Wyschnegradski and Liapounoff (Ljapunow)—research in stability theory is more intensive in Russia then in other countries. In consequense, various Russian books encompass a very substantial body of useful linear and nonlinear stability theory that is not to be found in control engineering texts of other languages (as evidenced, for example, in the recent text by N. Malkin, *Theory of Stability and Motion*, 431 pp. State Publishing House, Moscow, 1952).

Geronimus traces the development of certain phases of this branch of control theory through his accounts of the life and work of Wyschnegradski and of Liapounoff. Unfortunately, few control engineers can read Russian. Recently, however, the various portions have been issued as a series of inexpensive monographs in German translation. The two of interest here typify the series. Each comprises a full-page plate of the individual concerned, a short sketch of his professional career, a concise, detailed account of his most important technical work, and a list of pertinent references.

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are especially stressed. The latter was largely a detailed study of the nature of the stability of the Watt governor: as effected through account of the types of motion corresponding to the possible natures of the roots of the associated cubic characteristic equation; construction of the now-familiar stability diagram utilizing two coefficients of this equation as variables; division of this diagram into stable and unstable regions; a further subdivision of the stable region into subregions corresponding to oscillatory and nonoscillatory regions; and—seldom seen in a control text—a yet further subdivision of the nonoscillatory region into subregions arranged according to the all-real or complex conjugate roots of the characteristic equation. In view of this work Wyschnegradski is commonly termed "the founder of the study of control system theory in Russia". The principal value of the monograph to the control engineer is, perhaps, in its clear substantiation of Wyschnegradski's claim to this title.

Liapounoff's contribution to stability theory (especially the important basic theory advanced in his 1892 doctor's thesis) are encompassed in eight short chapters. Their essential content is well-eptomized in the chapter headings: 2. Stability of systems; 3. Liapounoff's direct method; 4. Integration of homogeneous systems of linear equations; 5. Stability in the first approximation; 6. Stability of nonstationary systems; 7. Equations with periodic coefficients; 8. Methods of development in terms of parameters; 9. The scientific work of A. M. Liapounoff. A concluding chapter gives an interesting account of the development of Liapounoff's theories and ideas during the past 65 years in the various centers of research founded by his early students, and of the role of these centers in the formulation of the current body of Russian writings on nonlinear control theory.

The chapters provide a very clear account of Liapounoff's methods and of certain other broad aspects underlying the analytic theory of the stability of nonlinear control systems. Application of theoretical content is well-illustrated by detailed solution of numerous numerical examples. Thus, this monograph provides an excellent introduction to the difficult domain of nonlinear stability theory—which is of rapidly increasing practical importance because of the growing emphasis on nonlinear control system design.

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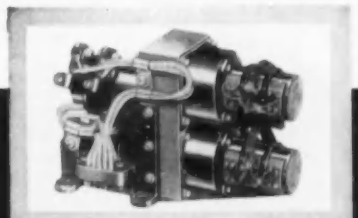

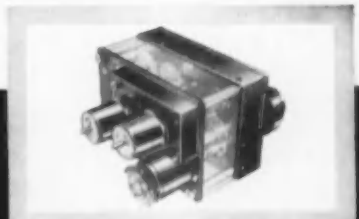

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trogradski: *Zum Prinzip der kleinsten Wirkung*) should be purchased with these monographs, for it contains the details of the references cited in the two items in the review.

. . . on More Math

METHODS OF CALCULATION BY THE AID OF [NUMBER] SEQUENCES (*Méthode de Calcul a l'aide de suites*). *Michel Cuénod, Ingenieur, OFINCO, Geneva, Switzerland. Published by Science et Technique, P. Feissly, Libraire-Editeur, 11 Petit-Chene, Lausanne, Switzerland. 19.50 Swiss francs (approx. $4.60).*

This monograph buttresses a series of very interesting articles wherein Cuénod investigated and formulated the theory and means of substantially improving the frequency regulation of a power system, especially when the energy is generated largely by hydraulic turbogenerators, as is the case in Switzerland. For these investigations, number series prove to be the ideal analytic tool. The engineer interested in this important aspect of power-system control engineering will find Cuénod's monograph of especial value.

More generally, however, all who have come to appreciate the manifold uses and power of number series calculation (as exhibited, for example, in the recent article on process control theory, J. B. Reswick, "Determine System Dynamics—Without Upset", in the June 1955 issue of CONTROL ENGINEERING) will find this excellent monograph worthy of close study.

In 1947 the English control engineer Arnold Tustin advanced "A method of analyzing the behavior of linear systems in terms of time series". Essentially, this comprised approximation of the forcing function by superposition of a series of appropriately chosen triangular pulses; representation of these by impulses of the same strength; and subsequent determination of system response by appropriate computation with the associated numerical sequences or "time series". Madwed considerably extended Tustin's initial work in a Dr. Sc. thesis at MIT in 1950. The original printing of this thesis was rapidly exhausted, but has recently been reprinted as *Number Series Method of Solving Linear and Nonlinear Differential Equations*, Report No. 6445-26, Instrumentation Laboratory, MIT, Cambridge Mass., about $2.00.

Cuénod's monograph, which somewhat parallels Madwed's work, was a Dr. Sc. thesis written at Zurich Poly-

technique Institute in 1952. Some subsequent additions delayed publication until 1955. It starts with development of basic theory, as does Madwed's, thus overlapping the latter in some basic detail. However, the difference in content is sufficiently great to be of interest. For example, his material on the application of number series in the control field is substantially different from that in Madwed's text.

The monograph splits into two sections. The first part, "Principles of calculation by the aid of sequences", comprises eight short chapters on basic definitions; operations with sequences; solution of linear differential equations of the first and second order with constant coefficients, of the linear difference-differential equation of the first order, of the differential equation of the first order with variable coefficients, and of partial differential equations; the relation of number series calculation to transform theory; and study of random functions. The work exemplifies the possibilities of time series computation, rather than exhaustive theory. Thus each topic is treated quite briefly. However, the development is clearly made and is supported by detailed numerical solutions of numerous electrical and mechanical systems problems.

The second part, "Application of calculation by the aid of sequences to the theory of automatic control", comprises four short chapters on basic definitions in control theory, effecting the limit of stability by a rather novel method, determination of transient response, and automatic control systems with several degrees of freedom (thus, with multiple inputs and outputs).

The volume concludes with a summary of various aspects of computation and other uses of sequences; four appendices (determination of the roots of a characteristic equation, study of the error involved in a computation with sequences, investigation of a certain hydroelectric control problem, and application of sequences in the study of random functions); nine useful tables of equations, basic correspondances, a bibliography of 44 references; and a detailed table of contents.

. . . on Automation

THE ROBOT ERA. *P. E. Cleator. 172 pp. Published by George Allen and Unwin, Ltd., Ruskin House, Museum Street, London, England, 1955. 16 shillings.*

The prime purpose of this book (and also a pithy characterization of its style!) is well-remarked in the publisher's comment: "The role of the

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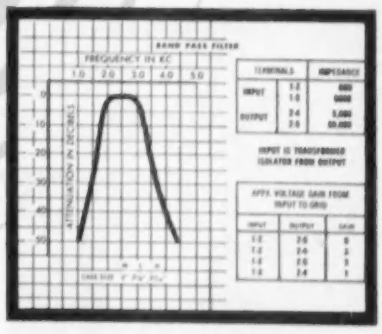

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machine in the Industrial Revolution of the 18th and 19th Centuries is a familiar enough story. But many of the machines which are now emerging are of a nature so startling that a new revolution may be said to be on the way. Here, prefaced by a note on the underlying principles involved, is a lively and eminently readable description of machines at work in the world today."

To facilitate this end—a readable description of machines at work in the world today—the author divides the book into three parts: a short "Part One: Wheels Within Wheels" (pp. 15-42); a longer "Part Two: Automata in Action" (pp. 43-90); and a yet-longer "Part Three: Machines Minus Men" (pp. 91-157).

Part One explains certain basic concepts, principles, and facts underlying operation of the machines under discussion. Thus, Chapter "I. Matters Mechanical and Metallurgical" outlines the basic theory of the lever and the inclined plane, and sketches developments to date in the preparation and use of certain basic metals, especially iron and steel. "II. Prime Movers and Power Sources" advances a brief account of the evolution of means for powering machines, from manual methods in the time of the Pharaohs to the diesel motor, gas turbine, and jet engine of today. "III. Elements of Control (Devices)" ranges over account of basic operation and especial merits of the mechanical governor, the magnetic relay, various types of thermionic tubes, and several semiconductor devices.

Part Two opens with an account "I. Mechanisms Emergent" of the gradual development of fully-automatic machines and describes in detail a number of industrial-type machines. Chapter "II. Robots in Our Midst" continues the description, but mostly of devices that affect personal life in one way or other. "III. Enter the Computer" details evolution, construction, and use of various modern computers. And "IV. From Matchlock to Deadlock" outlines the development of modern devices of warfare—from catapult to the hydrogen bomb.

In Part Three, "I. Autofabrication" outlines the rise and present state of the automatic factory; "II. Aspects and Implications" is concerned with the effects of the automatic factory on the social fabric of our time; "III. Power Without Precedent" details the discovery of fission and fusion and covers the present status of atomic energy; "IV. The Day After Tomor-

row" conjectures on the role of mankind in an era of cheap, unlimited power; and "V. The Electronic Brain" remarks on the storage, transmission, and utilization of information by electronic means.

This reviewer believes the book merits reading by anyone interested in the effects of automation on the personal, social, economic, and governmental life of the individual. Numerous excellent plates depict installations, machines, and constructions of British origin, and clever topical cartoons extracted from British journals provide good visual evidence of Britain's recognition of the vital role of automation in modern industry.

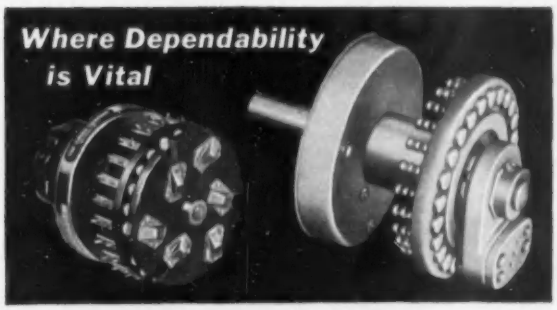
. . . on More Automation

OFFICE AUTOMATION: INTEGRATED AND ELECTRONIC DATA PROCESSING. *R. Hunt Brown, President of Automation Consultants, Inc.* 203 pp. *Published by Automation Consultants, Inc., 1450 Broadway, New York City.* $12.50.

This is a nontechnical reference manual on office electronics, written for anyone interested in office automation. The pages are assembled in loose leaf form, so that the volume can be kept up to date (through a yearly $25 service charge); the coverage, though comprehensive, is restricted to essential detail; and particular devices are discussed impartially. Facts and applications, rather than theory and construction, are emphasized; thus the account is largely descriptive and easily grasped.

The text is divided into 48 chapters assembled into six major sections. A good insight into the essential content is provided by citing the heading of each section and noting the number of chapters and pages constituting it. "Commercial Section I: Automation, benefactor of man, or progress without fear" (chaps. 1-8, pp. 1-33) is an account of different commercial aspects of office automation, with explanation of existing applications and opportunities in this rapidly developing domain.

"'Hardware' Section II: New machines for office automation and how you can use them" (9-29, 25-204) is a lengthy account of new office tools, such as common and native language machines for integrated data processing, including available communications services and associated equipment. Under review are telephone, telegraph, facsimile, and closed-circuit television facilities; keyboard and punched-card computing machines; electronic computers and associated memory systems, and high-speed print-



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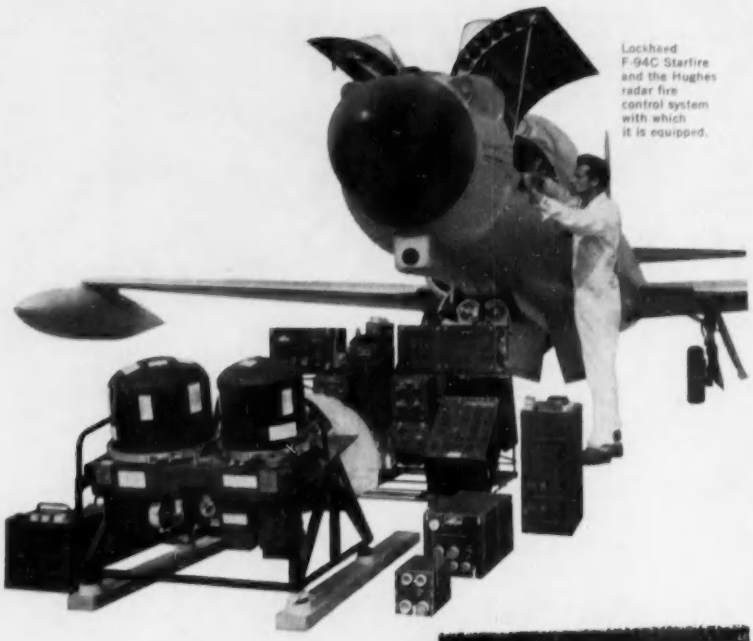

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ers. Emphasis is placed on the future and manifold possibilities of electronic computers.

"Accounting Section III: The new methods and procedures" (30-31, 205-212) is a short discussion of electronic and automatic accounting applications, with stress on the uses and benefits of recently innovated machines. "Sociological Section IV: Humanities of automation" (32-38, 205-234) remarks on social aspects of office automation. Prime emphasis is placed on the various ways in which modern office automation can alleviate much of the tedious drudgery of present-day conventional office work.

"Scientific Section V: The new techniques" (39-44, 235-250) states in nontechnical terms the essential aims and efforts in operations research, applied cybernetics, automatic programming, information theory, game theory, and associated topics. "Developmental Section VI: Applications 'just around the corner'" (45-46, 251-283) tells how many enterprises not yet using electronic machines could advantageously employ them.

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automation may find the section on "Hardware" (about 60 per cent of the total volume) of most interest. However, the development engineer, office manager, business executive, or other individual directly concerned with data processing, and the sales engineer concerned with establishing modern equipment for such purpose in office practice, should find special values throughout the book—and it is to this group that the text is especially directed.

. . . on Computers

PROCEEDINGS OF THE EASTERN JOINT COMPUTER CONFERENCE ON DESIGN AND APPLICATION OF SMALL DIGITAL COMPUTERS. 97 *pp. Published by the American Institute of Electrical Engineers, 33 West 39 Street, New York, N. Y.,* 1955. $3.00

A modern automatic digital computing machine falls naturally into one of three broad categories: large-scale fully-automatic machines; intermediate-size machines, based largely on magnetic drum storage; and partially-automatic computers entailing punched-card machines. These proceedings of the conference, attended by some 1,700 registrants at Philadelphia Dec. 8-10, 1954, under the sponsorship of AIEE, IRE, and the Association for Computing Machinery, are concerned with machines of the last two categories.

The construction, performance, applications, and relative merits of a number of American computing machines are discussed. Indicative of a strong current trend in computer design is the account of the Bell Telephone Laboratories TRADIC, prototyped largely of point-contact transistors.

Special components and techniques are covered in papers on high-speed punched-tape equipments, high-speed printers, magnetic-core circuits, and various procedures for increasing the efficacy of magnetic-drum systems.

The computer engineer will find these proceedings of value for the information they afford on important current advances in his rapidly developing field.

Thomas J. Higgins
Professor of Electrical Engineering
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Briefly noted

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Reactor Fundamentals

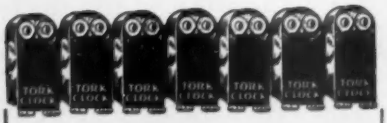
THERMAL POWER FROM NUCLEAR REACTORS. *A. Stanley Thompson and Oliver E. Rodgers, 6 by 9 in., 229 pp. Published by John Wiley & Sons, Inc., N. Y. $7.25.*

The control engineer creates control arrangements for systems and processes. To do a thorough job he must know at least the fundamentals of the process, particularly with respect to the variables that require control, and he must be aware of other factors such as safety to personnel and equipment. One of the newer processes attracting the attention of the control specialist is that of nuclear reactors.

Although this book deals primarily with nuclear reactors per se, the clear presentation of this fundamental material allows the interested reader to grasp the concepts without excessive effort.

The introduction should definitely be read, for it contains a description of a nuclear reactor and defines terms and concepts unfamiliar to persons not directly concerned with the field of nuclear energy. In exceptionally clear English and by means of fine layouts the authors describe nuclear considerations, reactor equations and critical mass, reactor kinetics, shielding, materials, and power extraction.

Since the subject is highly technical and involves some advanced math, they are often required to talk in these terms. But sufficient conclusions occur in the text to allow the reader in search of "gists" to gain some good insight into the machinations of the reactor. The book is peppered with succinct comments. For instance, after a lengthy dissertation on nonlinear behavior of reactors and reactor control the authors state, "It may well be that the nonlinear considerations are involved only in oscillations of such magnitude, in a power reactor, as to be only the result of an accident of which the consequences are very serious. In this case it is the prevention of the physical phenomenon which is important and not its mathematical analysis."



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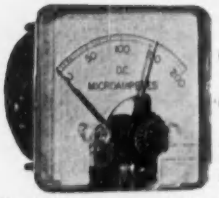

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Electronic Circuits for You

ELECTRONIC ENGINEERING. *Samuel Seely, Professor of Electronic Engineering, Syracuse University, 6 by 9 in., 525 pp. Published by McGraw-Hill Book Co., Inc., 330 W. 42nd St., New York 36, N. Y.*

This new book is intended as a companion volume to Professor Seely's *Radio Electronics*. Together they represent a revision and extension of the author's *Electron-Tube Circuits*. This book discusses in detail a wide variety of electronic circuits. Circuits that are important principally in radio are excluded here and covered in the companion volume. A number of circuits of interest both in radio and nonradio applications are included, however. Some of the material here is exactly duplicated in *Radio Electronics* to make both volumes independently useful.

Generally, discussion of a circuit begins with a physical explanation of its operation. The circuit is then analyzed mathematically to examine the effects of the various parameters on its operation and derive its mathematical description. Often several methods are used to demonstrate different analytic approaches.

The book spends considerable space describing and analyzing basic electronic elements and concepts that are common to many of the circuits discussed later. The first hundred pages are spent in this manner. The first chapter, 45 pages long, is titled "Characteristics of Electron Tubes." It describes, with due thoroughness, the electrical and physical characteristics of all kinds of vacuum and gas electron tubes—diodes and triodes, multi-element tubes, high-power amplifiers, thyratrons and ignitrons, simple glow lamps, and cathode-ray tubes, to name a few.

The next several chapters follow in the same vein and are titled: "Vacuum Triodes and Circuit Elements", "Basic Amplifier Principles", "Untuned Potential Amplifiers", and "Feedback in Amplifiers". Chapter 6, "Electronic Computing Circuits" (analog), opens the part of the book that discusses and analyzes specific electronic circuits of wide interest. Subsequent chapters are titled: "Special Electronic Circuits" (limiters, clippers, clampers, etc.), "Oscillators", "Heavily Biased Relaxation Circuits", "Saw-tooth Sweep Generators", "Special Sweep Generators", "Rectifiers", "Rectifier Filters and Regulators", and "Electronic Instruments".

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MARCH

Institute of Radio Engineers, National Convention, Kingsbridge Armory and Waldorf-Astoria Hotel, New York Mar. 19-22

American Society of Mechanical Engineers, Instruments and Regulators Div., Second Divisional Conference, Princeton University, Princeton, N. J. Mar. 26-27

APRIL

American Institute of Electrical Engineers, Southwest Meeting on "Electricity in Aircraft", 60 exhibits, Baker Hotel, Dallas, Tex. Apr. 2-4

Special Technical Conference on Magnetic Amplifiers, sponsored by American Institute of Electrical Engineers, Institute of Radio Engineers, Instrument Society of America, Hotel Syracuse, Syracuse, N. Y. Apr. 5-6

Scientific Apparatus Makers Association, 30th Annual Meeting, Belleview-Biltmore Hotel, Belleair, Fla. Apr. 8-12

International Exhibition on Instrumentation - Automation, Norwegian Industries Development Association, Royal Norwegian Council for Scientific and Industrial Research, Abelhaugen Halk, Oslo, Norway Apr. 9-22

American Management Association, Special Conference on Systems Planning and Control, including "Systems Role in Electronic Data Processing", $75 fee, Hotel Roosevelt, New York Apr. 23-24

American Institute of Electrical Engineers, Conference on Recording and Controlling Instruments, Bradford Hotel, Boston. Apr. 26-27

MAY

Instrument Society of America, Second National Flight Test Instrumentation Symposium, Hotel Texas, Fort Worth, Tex. May 6-9

Institute of Radio Engineers, National Conference on Aeronautical Electronics, 70 exhibits, Hotel Biltmore, Dayton, Ohio May 14-16

Symposium on Reliable Applications of Electron Tubes, RETMA Engineering Department, IRE Professional Group on Electron Devices, and JETEC, University of Pennsylvania, Philadelphia, Pa. May 22-23

American Society for Testing Materials, Fourth Conference on Mass Spectrometry, Netherlands Plaza Hotel, Cincinnati, Ohio May 27

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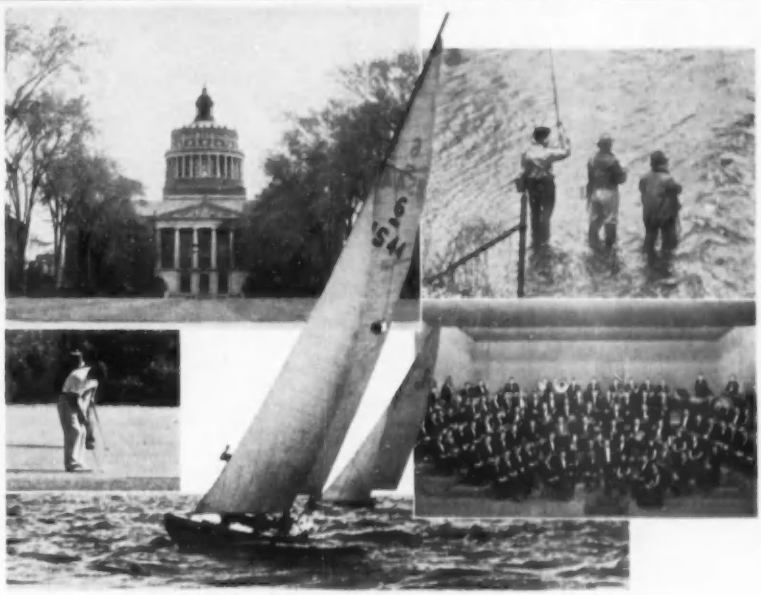

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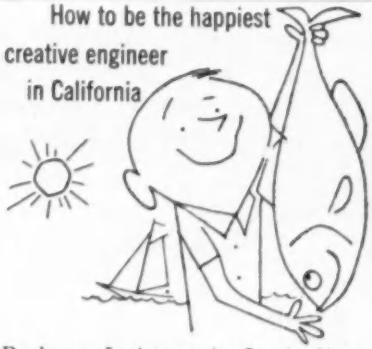

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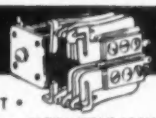

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